Volume 3 OCTOBER, 1924 Number 10

JOURNAL

OF THE

AMERICAN WELDING SOCIETY

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33 West Thirty-ninth Street, New York

American Welding Society

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AMERICAN WELDING SOCIETY

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AMERICAN WELDING SOCIETY
ESTABLISHED 1919
JOURNAL

Volume 3 October, 1924 Number 10

Program Fall Meeting American Welding Society

October 30th and 31st, 1924

Headquarters at

Hotel Winton, Cleveland, Ohio

THURSDAY, OCTOBER 30, 1924

Morning

10:30 A. M.—Registration **Hotel Winton**

From 10 a.m. to 11 a.m. members will be provided an opportunity to get together and renew friendships.

10:30 A. M.—Welding Wire Specifications Committee Meeting (Committee members)

Principal object is to consider specifications and standards submitted by other organizations for our comments.

11:00 A. M.—Address of Welcome

Members are expected to report promptly as one of the City or State officials, in addition to the President of the Society, will welcome our members to Cleveland. Mr. H. H. Dyar, Chairman of the Cleveland Section, will give a detailed explanation of each session on the program.

12:30 P. M.—Luncheon* **Hotel Winton**

An informal luncheon has been arranged at the Hotel Winton. Admission will be by the combination luncheon and dinner card issued by the Society to members.

Afternoon

2:00 P. M.—Inspection Trip **Starts from Hotel Winton**

Cleveland offers several opportunities for worth while inspection trips of interest to members in the American Welding Society. The Cleveland Committee has made arrangements to include a number of places on the tour such as a railroad repair shop, welded pipe line, and a plant of a manufacturing company. The party

will start promptly at 2 o'clock and transportation arrangements have been made to keep all the members together. These inspection trips have in the past proven entertaining and profitable.

Evening

7:00 P. M.—Barbecue Dinner* **Hotel Winton**

The Annual and Fall dinners of the American Welding Society are looked upon as "important events." This one will be something special. The Cleveland Committee have surrounded the details with a veil of secrecy. We are told, however, that it will be informal with a lot of good things to eat and some very unusual entertainment features. Admission will be by the combination luncheon and dinner card issued by the Society to members.

FRIDAY, OCTOBER 31, 1924

Morning

10:00 A. M.—Technical Session **Hotel Winton**

Electric Arc Welding as a Method of Fabricating Large Structures.—H. Goldmark, W. Spraragen and W. L. Warner.

Uses of Spot Welding in the Structural Field.—H. A. Woofter.

Gas Welded Structures and the Cutting Torch as a Tool in the Structural Field.—G. O. Carter and D. C. McGiehan.

Arc Welded Steel Building.—J. W. Turner.

Loosening of Rivets.—R. Kinkead.

Welding and cutting possess remarkable possibilities as a substitute for present methods used in the fabrication of large structures such as cranes, bridges and buildings, etc. Important facts, figures and test data will be presented by experts for the consideration of the members of the Society and leading executives of the steel industries. These papers will be illustrated by lantern slides.

12:30 P. M.—Luncheon* **Hotel Winton**

Directly after the technical session a luncheon has been arranged in honor of the important guests (Executives from the steel industry), who will attend the technical session. Admission to members will be by the combination luncheon and dinner card issued by the Society to members.

Afternoon

2:30 P. M.—Board of Directors Meeting **Hotel Winton**

An open meeting of the Board of Directors and all members of the Society. This session has been arranged to allow members an opportunity to assist the Board of Directors in discussing plans for promoting the welfare of the Society, including membership, Society meetings, Society publications, increasing number of sec-

tions, employment service bulletin and cooperation with other organizations.

4:00 P. M.—Meeting of Meetings and Papers Committee with Chairmen of Local Sections to discuss section programs

4:00 P. M.—Meeting of Membership Committee

Evening

8:00 P. M.— Y. M. C. A. Building

Motion Picture—Oxygen the Wonder Worker—F. E. Rogers, Air Reduction Sales Co.

This four reel film shows how liquid air is made, why it is possible to separate the gases of the atmosphere; how oxygen is extracted from the air; how the high temperature (6300 deg. Fahr.) of the oxy-acetylene flame is produced; how carbide is made and acetylene gas generated; how iron, steel, copper, brass, aluminum and other metals are welded; how steel and cast iron are cut; how the oxy-acetylene torch is adapted to mechanical cutting and welding; and how welding and cutting operations of great economical value are performed in some of the country's important industrial plants and railroad shops.

The Electric Arc.—T. A. Wry, General Electric Co.

A projector has been developed which will show what happens in metallic arc welding. The arc will be projected on a screen while in operation so it may be readily seen by all members of the audience.

Liquid Oxygen demonstration. F. E. Rogers, Air Reduction Sales Co. What are the possibilities of liquid oxygen? Come and see among other things mercury frozen so hard that it can be used as a hammer to drive nails, a rubber ball frozen so stiff that it will crack like glass from a blow of the hammer and an egg boiled hard and then changed back again.

A Thermit Reaction.—R. L. Browne, Metal and Thermit Corp'n. An actual demonstration of a Thermit Weld.

*The combination luncheon and dinner card referred to above provides for admission to the luncheon Thursday noon, dinner Thursday evening and the luncheon Friday noon. Price to members for the combination ticket $7.50.

OFF TO ATTEND THE FALL MEETING!

Now is the time to get out the old suit case and dust it off in preparation for a trip to Cleveland.

The Fall Meeting of the Society will be held in the above city on the 30th and 31st of October. Hotel Winton is to be the headquarters. Everything has been done that is humanly possible to make the meeting both entertaining and instructive.

In spite of all these efforts, however, the success or failure of the meeting depends entirely upon your assistance. Elsewhere in the Journal there is described the purpose of the technical session, which is, namely, to extend the use of welding in the

fabrication of bridges, buildings, cranes and similar structures. An idea of the importance of the meeting can be gained from the fact that prominent steel executives from all over the country have been invited to attend. If these busy men can afford to give up several days to come to Cleveland in order to keep abreast of the latest information, it certainly will also help our members.

Cleveland is known for its hospitality, and the officers and members of the Cleveland Section have made herculean efforts to provide inspection trips, demonstrations, dinners and get-together sessions that will amaze you. All that is necessary to put the thing over is your attendance. You owe it to the hard-working members of the various committees responsible for the Fall Meeting activities to be present in appreciation of their work for you.

FUNDAMENTALS OF ELECTRIC WELDING

In welding ½ in. plate of mild steel, it is possible to do it in a number of ways. For example, you might use an ⅛ in. electrode with 125 amperes or you might use a 3/16 in. electrode with 200 amperes. Again, the added metal can be deposited in one layer, two layers or three layers. Moreover the welding edges can be so beveled as to form a double vee, each vee extending one-half the thickness of the plate, or a single vee extending to the bottom of the plate. Again you might be forced to do the welding in a flat, vertical, horizontal or overhead position. What would be the relative strengths of the joints in these several cases where the welding was done with a good operator? We all have opinions on the subject. Most of us, however, would find it difficult, if not impossible, at the present time to actually assign definite percentages in each specific case listed above.

Recognizing the importance of having actual test data available on these different variables, there was started a comprehensive investigation during the war under the auspices of the Welding Committee of the Emergency Fleet Corporation. A large number of test samples were made up under proper supervision with competent welders. The war came to an end; funds for this, as well as for many other investigations, immediately ceased. In the case of these welded samples, however, they were not destroyed, but were carefully machined and stored away through the courtesy of the General Electric Co. and Electrical Testing Laboratories of New York. With the plans of the American Bureau of Welding turning in the direction of extending the use of welding in the structural field, the necessity for fundamental information becomes at once apparent.

The Electric Arc Welding Committee, under the chairmanship of Mr. H. M. Hobart, has accordingly been requested to devise ways and means for getting the samples tested. Fortunately, Union College has offered the services of its laboratory without charge. Our members, as well as the entire welding fraternity, will be pleased to know that testing of these samples will be started shortly.

Through the courtesy of National Research Council, which is conducting a scientific study of the fatigue properties of metals and the laws governing their behavior, at the University of Illinois, it was also possible to arrange to have the "fatigue" specimens tested by the University of Illinois without expense to the Society.

DO SOMETHING FOR YOUR INDUSTRY

In this issue you will find several technical papers dealing with the applications of welding in the structural field. These papers may be considered as the formal launching of a project by the research department of the Society (American Bureau of Welding) which has for its aims the extension of the use of welding in the structural field.

The possibilities of welding and cutting as used in the fabrication of buildings, bridges and cranes are well known to the welding experts but not to executives of fabricating companies, steel mills and legislators. Some service results have been obtained. In nearly all of these cases, however, the structure was designed for riveting and then welded. Competent engineers know that such methods do not bring the best results either in economies or in quality of product.

Reliable data are needed on all phases, including costs, time of construction, design of joints, testing methods, inspection, methods of assembly, etc. There is only one way to secure this information and that is through the cooperative effort of everyone concerned. The project is so large, the problems are so com-

plicated, that it requires the combined knowledge and wisdom of everyone connected with the welding movement to bring about successful solutions. Moreover, even with the laboratory facilities at the disposal of the American Bureau of Welding, the cost of investigation will amount to many thousands of dollars. You, as well as anyone else, can help. Before any investigational work can be undertaken it is necessary to carefully sift and digest all available knowledge. The proper way to get it before the people interested is to publish any existing information in the Journal of the Society. Later on, when the investigation is formally undertaken, you can help by getting the executives of leading corporations interested in the problem. You are urged to carefully read each page of this Journal and to submit discussions.

EDUCATIONAL COMMITTEE

In order that the excellent work of the Training of Operators Committee of the American Bureau of Welding may be, if possible, expanded upon and made more useful to the welding engineers, an Educational Committee has been appointed, whose function it is to explain in more detail the principles established by the Training of Operators Committee and to consider problems which require study and explanation, in order that everyone may have the benefit in comprehensive form of the experience of many.

DIRECTORY

Through a misunderstanding, the name of Malcolm Thomson, Turbine Engineer, General Electric Co., Lynn, Mass., Class B, was omitted from our directory.

List of New Members Since Publication of Directory

MEMBERSHIP

In the last issue of the Journal members were advised of the membership campaign being conducted by the Society to get new members. As stated in this issue, there will be a public acknowledgment to those who fulfill their obligation in getting at least one new member by printing in addition to the names of the new members the names of the proposers.

The names of new members secured since the publication of the directory are given below, as well as the names of the members credited with bringing them into the Society.

BOSTON

H. M. Steward (B), Superintendent of Maintenance, Boston Elevated Railway Co., 31 St. James Ave., Boston, Mass. Proposed by J. J. Flaherty.

E. L. Lockman (C), Assistant Engineer, Surface Lines, Boston Elevated Railway Co., 31 St. James Ave., Boston, Mass. Proposed by J. J. Flaherty.

William P. Kelly (D), Welder, 28a Plymouth St., Cambridge, Mass. Proposed by J. W. Morrissey.

Michael Kevelle (D), Welder, 238 Norfolk St., Cambridge, Mass. Proposed by J. W. Morrissey.

CHICAGO

Walter DeVries (B), Master Mechanic, Whiting Corp., Harvey, Ill. Proposed by W. P. Roberts.

J. B. Dunlop (B), Salesman and Service man, Oxweld Acetylene Co., 3642 Jasper Place, Chicago, Ill. Proposed by Geo. F. Schmid.

Fred B. Johnson, (B), Sales Engineer, Oxweld Acetylene Co., 3642 Jasper Place, Chicago, Ill. Proposed by Geo. F. Schmid.

George Rose (B), Engineer, Oxweld Acetylene Co., 3642 Jasper Place, Chicago, Ill. Proposed by Geo. F. Schmid.

Charles O. Watson (C), Salesman, Gibb Instrument Co., 551 West Van Buren St., Chicago, Ill. Proposed by W. H. Gibb.

Fred Blaes (D), Apprentice Boiler Maker, 2768 Taylor Blvd., Louisville, Ky. Proposed by Guy W. Bottorff.

Gerrit Evans (D), Welder, 14625 Clinton St., Harvey, Ill. Proposed by Stuart Plumley.

CLEVELAND

Robt. E. Kinkead (C), Engineer, Lincoln Electric Co., Coit Road and Kirby Ave., Cleveland, Ohio. Proposed by J. C. Lincoln.

NEW YORK

E. W. Ryder (B), Sales Representative, Morris, Wheeler & Co., 39 Cortlandt St., New York. Proposed by J. W. Meadowcroft.

Frederick Conlin (C), General Manager, Chemical Treatment Co., 26 Broadway, New York.

WESTERN NEW YORK

Howard D. Thomas (B), Welder, Merchants Despatch Trans. Co., East Rochester, N. Y. Proposed by G. W. Swan.

Edward S. Hebeler (C), Superintendent, Allan Mfg. & Welding Co., Inc., 726 Washington St., Buffalo, N. Y. Proposed by G. W. Swan.

John F. Mallon (D), Cleaning Room Foreman, American Radiator Co. (Arco Steel Dept.), 1807 Elmwood Ave., Buffalo, N. Y.

Felix Najeski (D), Welder, American Radiator Co. (Arco Steel Dept.), 1807 Elmwood Ave., Buffalo, N. Y.

Jos. H. Sander (D), Melter, American Radiator Co. (Steel Dept.), 1807 Elmwood Ave., Buffalo, N. Y.

PHILADELPHIA

Edward Evans (B), Manager, Fence, Culvert & Wire Products Dept., Horace T. Potts Co., East Erie Ave. and D Sts., Philadelphia, Pa. Proposed by J. W. Meadowcroft.

A. A. Ziegler (B), Manager of Sales, Morris, Wheeler & Co., 30th and Locust Sts., Philadelphia, Pa. Proposed by J. W. Meadowcroft.

George Kahmar (C), Foreman, American Pulley Co. (Res.), 141 W. Luray St., Philadelphia, Pa. Proposed by J. W. Meadowcroft.

Alan C. Walker (C), General Factory Foreman, American Pulley Co., (Res.) 4524 Smedley St., Philadelphia, Pa. Proposed by J. W. Meadowcroft.

J. Leutwyler, Jr. (D), Operator Welding, E. G. Budd Mfg. Co., (Res.) 7229 Claridge Ave., Philadelphia, Pa. Proposed by J. W. Meadowcroft.

SOCIETY

H. E. Josselyn (D), Purchasing Agent, St. John Dry Dock & Shipbldg. Co., Ltd., St. John, N. B.

SECTION ACTIVITIES

Philadelphia:

The October meeting will be held on the 20th in the Engineers' Club. J. H. Deppeler, chief engineer of the Metal & Thermit Corporation, will present a paper on the "Possibilities of Thermit—Past, Present and Future," illustrating same with motion pictures.

The Philadelphia Section has developed some careful plans for increasing membership in the Section. The Membership Committee has divided the city and each member of the committee has been assigned a specific section. The procedure will be to visit the companies who are interested in welding and advise them of the activities of the Society and the service which can be received through membership. New members as well as the proposer will be advertised in the Journal. Cooperation is being sought from the Philadelphia Safety Council, as in this way it is hoped to extend the use of welding.

In the last issue of the Journal, Philadelphia Night was given as Dec. 19. This should have been Dec. 15, 1924.

New York:

The first meeting of this section was held on the evening of Oct. 14 in the Engineering Societies Building. This opening session was termed "Get-Together Session" and also "Railroad Night." Moving pictures and lantern slides were featured on the applications of welding by the several processes in the railroad field and they were described by J. Weiss of the New York Central Railroad, W. H. Ludington of the Air Reduction Sales Co. and J. H. Deppeler of the Metal & Thermit Corporation. Cider, smokes and pretzels helped to add to the success of the meeting. About 100 people were present and keen interest was displayed in the various applications. A number of questions covering the various technical features were asked and satisfactorily answered.

An unusual feature of the meeting was something not on the program. This consisted of a six-reel motion picture showing Buster Keaton in action.

One of the methods adopted by the New York Section in getting new members was to distribute blank cards at the meeting with a request that everyone present write the name of at least one person who should become affiliated with the American Welding Society. These people will be interviewed by the Membership Committee.

A tentative program of the New York Section for the rest of the year is as follows:

Nov. 11—"Applications of Butt and

Spot Welding in Modern Industry," H. A. Woofter, Thomson Electric Welding Co.

Dec. 16—"Welding in the Oil Industry," F. C. Fyke, Standard Oil Co. of New Jersey.

Jan. 13—"The Possibilties of Thermit—Past, Present and Future," J. H. Deppeler, Metal & Thermit Corporation.

Feb. 3—"Purity of Oxygen as Effecting Economy in Cutting," Herman Van Fleet, Air Reduction Sales Co.

March 10—"Power Service for Electric Welding." Speakers to be announced later.

May 7—Subject and speaker to be announced later.

Chicago:

The October meeting of the Chicago Section was held on the 3rd in the rooms of the Western Society of Engineers. A paper was presented by A. M. Candy of the Westinghouse Electric & Manufacturing Co. on "Electric Arc Process of Reclaiming and Scrapping Steel Freight Cars." A lengthy discussion followed on the relative merits of gas and electric arc for cutting of rivets and methods to be followed to get the best economies by each process.

The next meeting will be held on Nov. 17, at which time David Ahldin and Keith Dunham will present a paper on "Acetylene."

Western New York:

The first meeting of the Western New York Section was held at Carnegie Hall, University of Rochester, on Sept. 17. Mr. W. B. Miller, metallurgist of the Pfaudler Company, presided. The speaker of the evening was C. J. Holslag of the Electric Arc Cutting & Welding Co., who talked on A. C. welding and also touched upon gas and direct current welding.

The October meeting of the Section will be held at the Technical High School, Buffalo, N. Y., at which time R. M. Swan of the Metal & Thermit Corporation will present the paper, "Thermit Welding," accompanied by several demonstrations.

Boston:

The Boston Section announces their program for the coming year as follows:

Oct. 24—H. A. Woofter will present a paper on the "Advantages and Scope of Applications of Resistance Welding in Industrial Manufacturing." Particular attention will be given to the developments in the past year. Several demonstrations of resistance welding will be shown. The place of the meeting will be the plant of the Thomson Electric Welding Co. at Lynn.

Nov. 21—C. A. Adams and C. J. Holslag will present papers at the Boston City Club. Subjects to be announced later.

Dec. 19—S. W. Miller of the Union Carbide & Carbon Research Laboratories will present a paper on "Welding with Bronze."

Jan. 23—Prof. A. S. Kinsey, Stevens Institute of Technology. Subject to be announced later.

Feb. 20—R. L. Browne and C. A. McCune. Subjects to be announced later.

March 20—Dr. A. Krebs, General Welding & Equipment Co. Subject to be announced later.

April 17—Prof. V. O. Homerburg and C. E. Littlefield. Subjects to be announced later.

Pittsburgh:

The October meeting of the Pittsburgh Section will be held on the 17th in the office of the Smith Metal Perforating Co. A. Smith, manager, will present a paper on "A New System of Arc Welding and Cutting," after which he will give a demonstration of same in his shop.

San Francisco:

The September meeting was held on the 19th. E. W. King, welding foreman of the Standard Oil Co., Pipe Line Department, presented an interesting paper on the "Uses of Welding in the Oil Fields." The paper was illustrated by lantern slides and showed how welding is saving the oil field operators money and time.

Help Make the Fall Meeting a Success.

Plan to Attend.

EMPLOYMENT SERVICE BULLETIN

Opportunities.—The Society is glad to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN.

Services Available.—Under this heading brief announcements (not more than seventy-five words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period, names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Society's Office not later than the thirtieth of the month if publication in the following issue is desired. *ALL REPLIES should be Addressed to the number Indicated in Each Case and Mailed to Society Headquarters.*

Positions Vacant

V-18. Acetylene welder wanted in Philadelphia, experienced in all metals. Full particulars first letter, hourly rate and names of employers for past three years. Electric welding knowledge helpful but not essential. Expenses refunded if competent after three months.

V-19. Electric welder wanted in Philadelphia with cast iron experience. Full particulars first letter, hourly rate and names of employers for past three years. Acetylene welding knowledge helpful but not essential. Expenses refunded if competent after three months.

Services Available

A-18. Experienced oxy-acetylene welder desires position. Have had 9 years' all around experience as welder and in machine shop work. At present located in Brooklyn.

A-23. Welder desires position. Have taken the General Electric Training Course and have had five months' experience with the General Electric Co. on welding wheels, oil switch vessels, gear cases and welding tanks with semi-automatic welding machine. Have also had four years' experience with Ferrocarril Central Dominicano R. R., welding oil tanks, building up shafts for locomotives, frogs, cast iron gears, locomotive frames, etc.

A-24. Acetylene welder desires work in Philadelphia or vicinity. Have had four years' experience in welding all metals.

A-25. Electric arc welder desires position. Have taken the General Electric Training Course and have had two years' experience with the General Electric Company welding various kinds of oil switch tanks, gear cases, and structural steel work.

A-26. Welder available. Am 27 years of age and have had railroad experience for over a year in New York Central and Lackawanna Railroad with both the electric arc and acetylene welding. Have welded all kinds of metal and set up own work. Have been with shipyards and small boiler shops. Can do overhead welding with either electric arc or acetylene. Would like a position within short commuting distance of New York City.

A-27. Six years' experience as welding engineer. Theoretical and practical work. 2½ years in South America as Welder for International General Electric Co. Married. Speaks Spanish fluently. Willing to go anywhere.

Uses of Spot Welding in the Structural Field*

By H. A. Woofter†

Until fairly recent years, the hot driven rivet ruled supreme in the structural field. It was monarch of all boilers, bridges, trusses, building frames, smokestacks, steel ships, automobile bodies, etc., too numerous to mention. The practice of riveting was adhered to, in large measure, simply because it had always been done that way, and no effort was made to find a better and cheaper method.

In recent years, however, the hitherto undisputed domain of the rivet is rapidly being encroached upon by electric welding in some of its various methods. Already steel automobile bodies, iron stairways and ventilators on battleships, smokestacks, cutter bar segments for mowing machine blades, metal furniture, automobile parts, disc wheels, steel culverts, and many other articles are being spot welded throughout, instead of being riveted, and the use of spot welding is increasing for structural purposes every day. The reasons for the change from riveting to spot welding are many—some of which are greater strength, greater production, lower cost, cleaner, and no money outlay for rivets, drill presses, drills, pneumatic hammers, dolly bars, forges or fuel. The greater strength of the spot weld versus rivet is shown in Figure 1.

A Convincing Test of Spot-Welding

Welds hold over sixty per cent more than rivets on actual tests.

Riveted and welded pieces shown in Fig. 1. Tested at the Lunkenheimer Laboratory in Cincinnati. We give their report as follows:

No. 1. Spot-welded in one place—broke at weld at 1625 pounds.

No. 2. Spot-welded in two places, also two rivets—broke at rivets at 1555 pounds.

No. 3. Spot-welded in three places—broke outside weld at 2715 pounds. (Notice elongation of metal.)

No. 4. Spot-welded in three places, also three rivets—broke at rivets at 2055 pounds.

No. 5. Solid lap weld—broke outside weld at 2720 pounds.

No. 6. Butt-welded—broke at weld at 2555 pounds.

No. 7. Spot-welded in one place, and riveted once—broke at rivet as 990 pounds.

No. 8. Solid lap weld—broke at weld at 2425 pounds.

No. 9. Spot-welded in two places—broke at weld at 2275 pounds.

No. 10. Plain piece of hoop iron, not welded—pulled apart at 2690 pounds.

Carefully Compare These Tests

Test No. 1. One Spot-Weld: broke at 1625 pounds.

Test No. 7. One Rivet: broke at 990 pounds. The weld stood 60 per cent more than the rivets.

*To be presented at the Fall Meeting, A. W. S., Cleveland, Oct., 1924.

†Electrical Engineer for Thomson Electric Welding Company and Thomson Spot Welder Company, Lynn, Mass.

Test No. 9. Two Spot-Welds: broke at 2275 pounds.

Test No. 2. Two Rivets: broke at 1555 pounds. The weld stood over 60 per cent more than the rivets.

Test No. 3. Three Spot-Welds: broke outside weld at 2715 pounds.

Test No. 4. Three Rivets: tore apart at 2055 pounds.

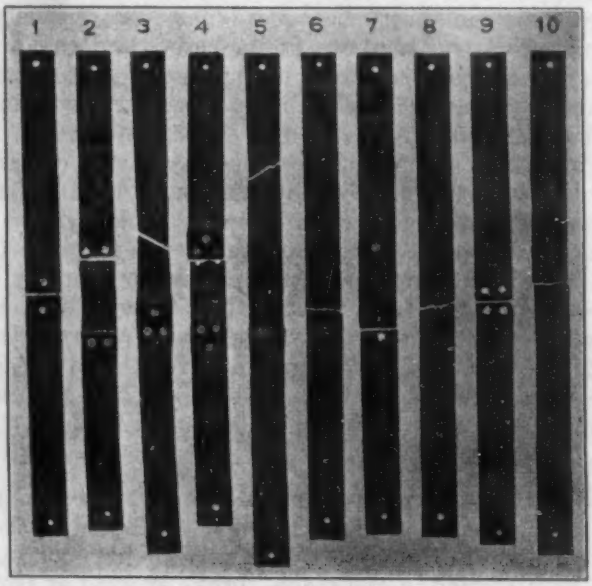


Fig. 1

Further proof of the superiority in strength of a spot weld over a rivet of same diameter is shown in Figure 2 and Figure 3. These specimens were broken by pulling in an Olsen Testing Machine, and were selected at random from a large number of specimens all showing results as illustrated.

Two unusual cases where the rivet has been superseded by spot welding are shown below. Figure 4 shows the hanger arms spot welded on to the crank case of one of our most popular automobiles. Figure 6 illustrates a new use for spot welding, which gives nearly ten times the production that was formerly got by the old riveting or bolting process. Figure 5 is self-explanatory and demonstrates that brass can be spot welded as easily as steel.

Probably the first successful employment of spot welding to heavy structural work was that of Mr. Osborne's freight car, figures 7 and 8, built in 1911, and which has been in service ever since, without failure of any of its numerous spot welded members. This case demonstrates the feasibility and safety of building steel freight cars by the spot welding process.

The spot welder can also be used to build up a ladder or grating of the same shape and appearance as the present standard type

by butting the end of each rung on to the side of the strap. Very special electrodes are required to get the heating effect at the proper place. Instead of a straight strap for the supporting frame an angle iron is used and a short length on each end of the rung is welded to one flange of the angle as shown in Figure 9. In making the weld the underside of this flange rests on a flat topped electrode

Fig. 2

Three thicknesses—two ⅛-inch on outsides of one ⅞-inch. A ⅛-inch rivet and a ⅛-inch spot. Tested by pulling against each other. *Rivet sheared—spot held*

Fig. 3

Three thicknesses—two ⅛-inch on outsides of one ⅞-inch. Two spots at each end of outside pieces. Pulled in testing machine. *Spots held—outside pieces were broken*

Fig. 4

Spot welded arm to crank case. Three-fourth inch diameter spots on two ¼-inch pieces. Five spots only 1¼ inches between center

Fig. 5

Two ⅞-inch spots, 1 inch apart, on two 3/32-inch pieces of brass. Chisel driven between, full diameter hole pulled out

Fig. 6

Mowing machine cutter bar. Three thicknesses, two ⅞-inch on top of one ⅞-inch. Forty-one spots per bar; actual production over long period, 250 bars per ten-hour day

while the rung is held in a V-shaped groove in the upper electrode. A welded grating can be made at a considerable saving of time and labor over the riveted grating.

During the war, the practice of spot welding ventilator funnels, smokestacks and stairways for the destroyer fleet was adopted, and is still in use.

The first attempt, so far as I can determine, to employ the spot welding process to the construction of steel ships was in 1917, when war requirements demanded the greatest possible speed in

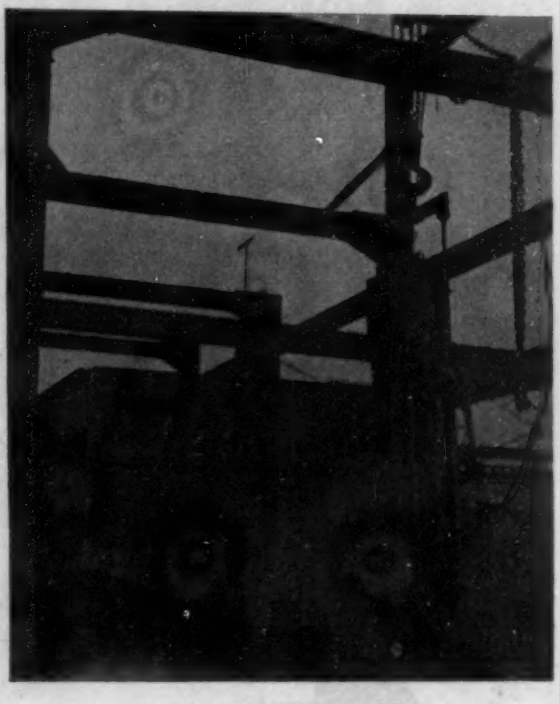


Fig. 7—Welder Fastening the End Sheet to the Floor Sheet

constructing the Emergency Fleet. Several large spot welders for this purpose were constructed in 1918, the largest of which, known as the Duplex Spot Welder, Figures 11 and 12, because of its making two spots at once, was designed by Mr. J. Murray Weed. The spots were each 1½ in. in diameter, made in approximately 30 seconds, using about 50,000 secondary amperes, and 60,000 pounds pneumatic pressure to complete a weld on two ½ in. steel plates. It had a 6 foot throat gap to permit the insertion of 6 feet, width of plates for spot welding. This welder was stationary and the work was brought to the welder. A complete description of this welder is found in a paper by Mr. H. M. Hobart, entitled "Welding Mild Steel," and presented before the American Institute of Electrical Engineers in New York, February 20, 1919.

During the latter part of 1918, two portable spot welders were built for the Brooklyn Navy Yard. They were designed to be suspended from a crane, and could be operated horizontally, vertically, or at any desired angle.

A fairly wide use has been made of spot welding for several years in the manufacture of metal lath, and steel reinforcements

Fig. 8—One of the Main End Sheets. The Bath Tub Section Stiffener Across the Center of the Sheet was Spot-Welded in Place as Well as the Top Chord Angle

for cement and concrete work. One of the large manufacturers of this class of material is the Albert Oliver & Son Company of New York City.

One of the latest uses of spot welding is in the manufacture of a patented steel joist for fireproof buildings made from three separate members—two angle irons 3 in. x 3 in. x ⅜ in. thick for the top and bottom members, and a 1 in. x ¼ in. bar with 90 deg. staggering forming a skeleton web and spot welded successively at top and bottom.

Still another type of joist is made in a similar manner, but uses 6 in. x ¼ in. channel iron for the top and bottom members, and a 2 in. x ¼ in. staggered bar. The readings taken when welding these joists are shown in the following table No. 1.

TABLE No. 1

Type	Pri. Volts	Pri. Amps.	KVA.	KW.	No Load Sec. V.	Time in Seconds	Power Factor	Approx. Pressure Lbs. Per Sq. In.
Angle.....	352	220	78.0	68.0	6.1	1.0	.873%	7,100
Angle.....	348	240	84.	68.0	6.1	1.0	.81%	7,100
Channel...	360	220	79.3	64.0	6.1	1.2	.81%	7,100

The following drawings, Figures 13 and 14, will serve to illustrate the general structure of these joists.

There were formerly four principal reasons why spot welding had not been employed in large structural work such as steel building frames, bridges and ships.

First. The reactionary reason that this type of construction had always been riveted, and therefore, that was the only way.

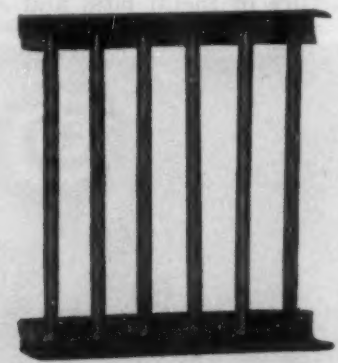


Fig. 9—Grating Constructed on Spot-Welding Machine

Second. No definite data existed regarding power requirements —whether the maximum demand, or the cost, would make prohibitive the use of spot welding for such large members.

Third. No one had ever built such large spot welders, because there had never been a demand for them.

Fourth. It was believed that the enormous pressure of from 30 to 60 tons necessary to press ship plates, steel girders, etc., into actual contact, and to consummate a spot weld, could not be carried by copper electrodes—copper being the only known substance at that time that would carry sufficient current to heat the spot.

Fig. 10—Steel Plate Reinforced by Spot-Welding an Angle Iron to it

Now, however, these four principal reasons for not adopting spot welding for large structures no longer exist.

First. Architects, engineers and contractors are now willing to adopt any method that will save them time and money, and the insurance companies, National Inspection Boards, and railroad and steamship officials have recognized and approved the spot welding process in many instances.

Second. Definite data now exist regarding the power demand, and showing the saving in cost of labor and material by the use of the spot welding process.

Third. Large spot welders have been and can be built with high power factor and efficiency, and of either stationary or portable type.

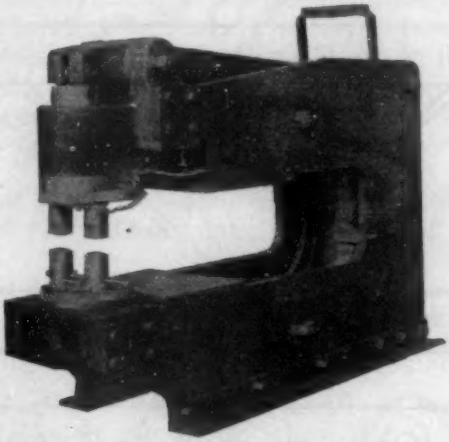


Fig. 11—View of Duplex Electric Welder Having a Reach of 6 Ft. Welds Two Spots at a Time

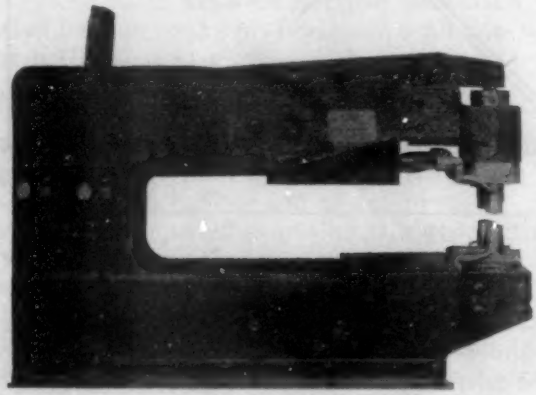


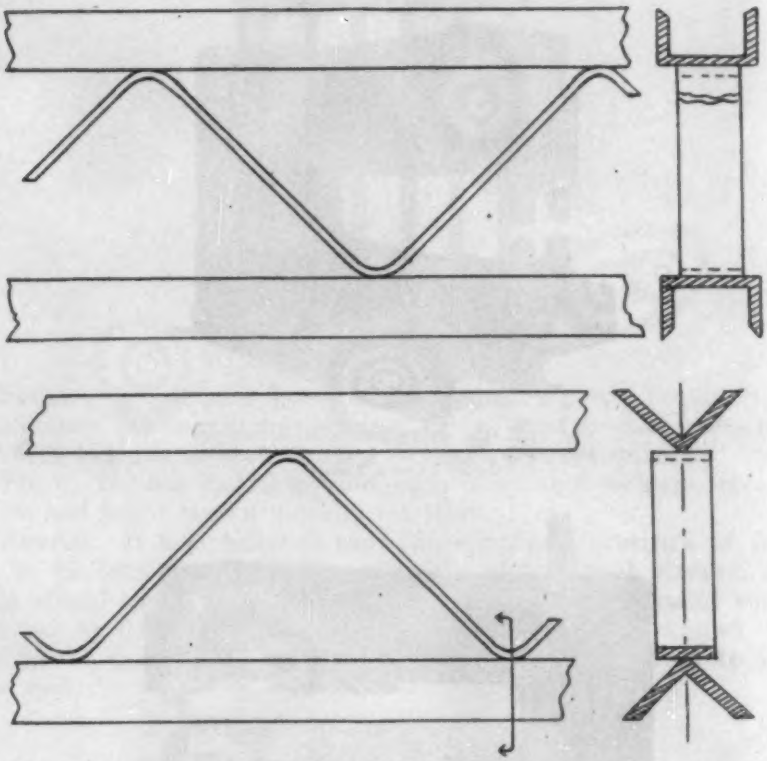
Fig. 12—Side View of Above

Fourth. A new method is now available to take care of the enormous currents and pressures impressed on large spot welders which were formerly considered prohibitive.

There would be two distinct types of spot welder required for general structural use—a stationary type, which would be best adapted for all inside work, such as the manufacture of fabricated steel buildings, bridges, etc., and a portable type handled by a crane for outside construction and erection.

There is another field for spot welding in connection with marine

work and salvaging that offers considerable possibilities. It is the ability to spot weld under water—either fresh or salt. In 1919, considerable experimenting was done along this line in connection with a project to salvage ships sunk during the war, which demonstrated that just as strong spots could be welded under water as in air. It requires an especially designed welder, or at



Figs. 13 and 14—Steel Joists

least special adaptations on a standard type of welder to make it suitable for under-water operation.

It should be noted that while the best spot welders of ten years ago had a power factor on 60 cycle circuit of from 60 to 66 per cent and the poorer ones had power factors around 35 per cent, it is now possible to design and build spot welders having power factors all the way from 80 per cent to 98 per cent on 60 cycles, and even a higher average on 25 cycles. These improved power factors help out the power situation enormously, and have a tendency to circumvent one of the principal objections of the power companies to the spot welder load. It is apparent that the maximum demand of the present spot welder would be less than half that of the old low power factor type.

The most extensive and convincing series of tests ever made on

large structural members, so far as we know, was carried on by Mr. L. B. Tuckerman, Engineer Physicist, Bureau of Standards. Mr. Tuckerman's paper, among other things, states in effect as follows:

Forty-two tensile specimens, 6 girders and 6 columns representing similarly made riveted and welded members were tested to destruction. The riveted members were furnished by the American Bridge Company, all rivets being $\frac{5}{8}$ in. in diameter and the punched holes 11/16 in. diameter.

Ultimate Strength Tests. Ultimate strength tests on the two sets of specimens showed a ratio of 1.15 in favor of the welded specimens.

Yield Point at Joint. This showed an average of 0.68 for riveted joints and 0.80 for welded joints, or a ratio of 1.17 in favor of welded joints.

Elongation at Joint. The average ultimate elongation was 0.240 in. for riveted and 0.219 in. for welded joints, which indicates that at rupture a riveted joint undergoes greater deformation than a welded joint.

Elongation Tests. These showed a ratio of more than unity in favor of the welded specimens.

Ultimate Strength and Proportional Limit. The ultimate strength of welded and riveted girders is practically the same.

Deflection. The ratio between vertical deflection at the center and the applied load up to the proportional limit was approximately the same for both types of construction.

COLUMNS:

Ultimate Strength. The ultimate strength of the welded column is lower than for the riveted column. The average ratio is 0.87.

Mr. Tuckerman's conclusions are as follows:

1. The welded joints tested in tension at higher ultimate strength than the riveted joints.

2. No appreciable difference was noted between the strength of the riveted and welded girders.

3. The welded girders were more flexible than the riveted, the apparent modulus of elasticity in cross bending averaging 5½ per cent lower.

4. The welded columns averaged 13 per cent weaker than the riveted columns. This difference may have been due to their greater flexibility. These columns could be stiffened by using larger welds or spacing them more closely.

5. As the strength of these welded and riveted members did not differ greatly, it is possible that spot welding may successfully replace riveting for structures fabricated from rolled steel, providing the cost of welding is not prohibitive.

We confidently believe that within the next decade the use of spot welding will have gone a long way toward replacing riveting and bolting in all large structural enterprises.

Use of Electric Arc for Welding Structural Steel*

R. E. KINKEAD†

Manufacturing in the metal working industries is largely a problem of fastening pieces of metal together, whether the finished product be a locomotive, bridge, aeroplane or automobile. Riveting pieces of metal together is a method as ancient as the history of the Mechanical Arts. The use of the threaded bolt was a development of medieval times. The use of soldering and brazing was known in the halcyon days of the Roman Empire.

Fusion welding is relatively such a new development as to have no standing whatever in history. Yet it appears possible in the light of achievements in the last twenty years that the whole of the Mechanical Arts must be revolutionized in view of the new development.

If this period in our civilization could be identified by a symbol, that symbol would be a Question Mark. Practical men of science are overhauling all of their practices and customs, and inquiring why we do this, why we do that and whether or not a better way may be developed.

The practice of riveting structural steel together has not escaped the searching inquiry in this direction on the part of the practical man of science. The point has been reached at which we inquire why it is necessary to punch a beam or column section full of holes in order to assemble it; why is it necessary to use from 30 per cent to 50 per cent more material to get the same strength due to the fact that we have punched the material full of holes? We are inquiring whether or not the fundamental difficulty of the riveted joints, namely, that the rivets work loose, may not be eliminated by a different and better method of fastening the pieces of metal together.

We cannot expect to answer that it has always been done that way and therefore that is the best way to do it.

On the average, we do know that structural steel pieces may be welded together at about one-third the labor expenditure involved in riveting them together and we must answer the question which is squarely up to this industry at the present time: "Why can't we weld the structural steel members together and save money?" There is no escape from that question. We must either do the job or give a satisfactory and conclusive answer as to why it can't be done.

In line with the philosophy of that incomparable engineer, C. F. Kettering, President, General Motors Research Corporation, "A

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*To be presented at the Fall Meeting, A. W. S., Cleveland, Oct., 1924.

† Engineer Arc Welding, Lincoln Electric Co.

problem thoroughly understood is partially solved." One of the difficulties with riveted joints is that the rivets work loose. It is interesting to speculate upon what makes rivets work loose. We have reproduced the riveted joint in rubber and studied the flexure in that material with the end in view of answering that question. What we have done in taking rubber as the material in this case is merely to decrease the modulus of elasticity. We have increased the deformation under stress to the point where it is no longer necessary to measure it with micrometers—we can see it with the naked eye. All of the conditions remain the same for practical purposes with the exception of deformation under stress. Upon the application of the stress to the riveted joint fabricated of rubber, we see clearly some of the things that happen in a riveted steel joint. In the first place, owing to the reduced section of material due to the punching of rivet holes, deformation through the reduced section is greater than the deformation through the original section and we may safely assume that the deformation is inversely proportional to the section. This deformation occurs in three dimensions: the length, breadth and thickness of the section which has been pierced by riveted holes have all changed. The rivet experiences some deformation and wear on its surface due to the movement of the pieces joined. It is at once evident from this study that under stress the rivet does not fill the rivet hole, regardless of how completely the rivet filled the rivet hole under no load conditions.

This would appear to lead us in the direction of the solution of the problem as to why rivets work loose. If the rivet doesn't fill the rivet hole under load conditions, it is reasonably certain that water or atmospheric moisture will get between the rivet and the rivet hole and that eventual loosening of the rivet will occur in the same manner as freezing water causes failure in a concrete street or sidewalk.

On a static load, it would be reasonable to expect that a much longer time would be required to work a rivet entirely loose than in the case of a live load, for the same reason that rapid freezing and thawing will destroy a concrete sidewalk or road in much less time than occasional freezing and thawing. We may perhaps safely assume that the period during which the rivet remains tight is inversely proportional to the number of applications of live load. The matter of fatigue of metal bears on this subject also, if the load on the riveted joint is more than the designer calculated it to be. If the riveted joint is subjected to a live load stress on the material which has been pierced by rivet holes beyond the true elastic limit of the material, the rivet will become loose due to the permanent deformation of the rivet hole by fatigue.

The human factors which enter into the fabrication of riveted joints are important. In the above discussion, we have considered the fundamentals which enter into the problem of determining what makes a perfect rivet work loose, and all rivets are not per-

fect, a fact to which any rivet inspector will enthusiastically subscribe. The reasons why rivets are not perfect are as follows:

First—Rivet not driven tight.

Second—Rivets overheated.

Third—Rivet holes not properly reamed.

Fourth—Rivets not driven in line with the axis of the center line through the head.

It seems to be universally agreed among rivet experts that you can't tell what the strength of a riveted joint is unless you have seen the joint made and inspected it after it has been made.

The above described problems in connection with riveting practice are very real and millions of dollars are expended every year maintaining structures on which the rivets work loose.

If we are to answer the question: "Why can't structural members be welded together?" we will have to answer that we don't know of any good reason why the job can't be done. The next question we would be asked would be: "If you don't know why it can't be done, why don't you find out?" That is exactly the situation in the industry at the present time.

In pursuit of our problems we are led naturally to the question of what makes welds fail. Unlike the case of riveting, the weld does not work loose, then fail. It fails without loosening. It may be safely stated that the only reason any weld designed for a particular service fails is that we did not know how to design the welded joint to carry its load without failure, and that is the gist of the whole problem in connection with the welding of structural steel. We know something of the limitations of the welded joint. Enough, we believe, to solve any question of design of a joint for a particular service. If we fail to observe the limitations of a welded joint, it will fail as surely as water will run down hill, and for the same reason, namely, obedience to natural law. The limitations of the welded joint are:

First—It has no reliable degree of ductility.

Second—The application of heat to the hot rolled steel to make the weld results in cast metal adjacent to the line of fusion in the hot rolled metal.

This cast metal does not have the same degree of ductility as the original hot rolled section. There is no method with which we are familiar at the present time by which we can avoid changing the metal in the hot rolled section adjacent to the line of fusion into cast metal. With these limitations in mind the joint may be designed which will withstand practically any stress ever encountered in the fabrication of structural steel. There are details and ramifications in the applications of these fundamental welding principles with which as yet we are not familiar. The facts are there and it is only a question of our ability to see them. One of our principal difficulties has been that in the welding industry we have had no experience in figuring structural steel jobs and we could not go out of the welding field for information and coop-

eration for the reason that all of the riveting experts have agreed that the job cannot be done. But as is usual in such cases, their chorus: "It can't be done" has been rudely interrupted by men such as Mr. Macomber of the Massillon Steel Joist, Mr. Field of the Baltimore & Ohio Terminal Railroad, F. R. Patch Company, Rutland, Vt., and many others who are doing it.

Our answer to the question: "Why can't structural steel members be welded together?" is that there is no reason other than our regretable ignorance and lack of physical conception of what happens when a load is applied to a structural steel beam or column. It is a relatively short step to that knowledge and understanding which we will make as soon as limited mental capacity and other intellectual inertia can be overcome.

Welded Ship Completely Water-tight*

The first ship constructed entirely under the welding system has proved in actual experience that this class of vessel stands the test of stranding, and advocates of the welded ship have every reason to congratulate themselves on the success which has attended the steamship Caria, built by Messrs. Camell Laird & Co., on the welded system in 1920. The Caria is at present in Messrs. Camell Laird's yards at Birkenhead, and has been inspected in her damaged condition by some of the most eminent naval architects and shipbuilding officials of the country, who are delighted with her condition after the test through which she passed on the occasion of her stranding.

Story of the Stranding

The Caria, a steel screw steamer of 398 tons gross register and 185 tons net register, owned by the Manx Isles Steamship Co., Ltd. (Messrs. Lowden, Connell & Co., managers of Liverpool), was on a voyage from the Manchester Ship Canal to Belfast with a full cargo when, unfortunately, she struck one of the sand banks in the upper reaches of the Mersey. She remained fast on the bank during the ebb tide and at low water strained herself considerably, but owing to her particular type of build, and the fact that there were no rivets in her, she remained absolutely water-tight during the whole of the period, although a considerable part of her length at the bilges was partly set up to the extent of about 14 or 15 feet.

On the next rising tide she was floated off, and after being sounded it was found that she was perfectly water-tight, and she proceeded on her voyage to Belfast, where her cargo was discharged in excellent condition. After the discharge of the cargo she was again thoroughly examined, and still found to be water-tight. It was, therefore, decided that she should return to the

*Reprinted from *Journal of Commerce*, July 17, 1924.

Mersey, but as a precaution a salvage pump was placed on board in case of necessity.

She duly arrived back in Liverpool, the salvage pump not having been required. The Caria subsequently entered Messrs. Cammell Laird's yard at Birkenhead, and was dry docked on the following day. A thorough examination was then made of the whole length of the ship, and it was found that there was not a single break in the hull, although, as already stated, she was badly set up.

If the Caria had been of the riveted class doubtless the rivets would have been opened up and sheared, and it is doubtful whether they would have been able to get her off the bank, as the seams would have opened up and the water would have entered the vessel. In any case, she could certainly not have continued her voyage to Belfast.

This severe test through which the Caria passed demonstrated very effectively the triumph of the welded ship.

An All Welded Steel Building*

J. W. TURNER†

The General Boilers Co. has been a pioneer in applying scientific engineering principles to the art of welding. In their plant arc welding has been applied to many processes other than to the construction of boilers. They recognized the adaptability of arc welding to the construction of structural buildings, and have built several steel buildings, using the electric arc to the exclusion of rivets.

Figs. 1 and 2 apply to either of two buildings, one 25 ft. by 85 ft. and one 25 ft. by 50 ft., which were constructed as part of their boiler plant during the latter part of 1923. Both buildings are single story, 11 ft. high at the eaves, and are used for manufacturing purposes.

The chief advantages in this method of construction are:

1. Makes detailing easier
2. Makes fabrication cheaper
3. Eliminates some members
4. Makes for greater flexibility
5. Makes for cheaper erection.

The detailing is easier, as there are no rivet holes to spot and no gusset plates or other connecting members to lay out. When the members are layed out in their proper relation and with the proper strength the design is complete.

The fabrication is cheaper because there are no holes to spot or punch. The members are simply cut to shape and marked.

When using welding it is possible to eliminate many gussets, clip

*To be presented at Fall Meeting, A. W. S., Cleveland, October, 1924.
†Engineer, General Boilers Co.

angles, etc. The parts of the structure may be fastened at any angle with each other without the use of screwed members.

The welding method allows greater flexibility during construction. Any changes or additions may be made with no more trouble than regular work, because there is no laying out and drilling or punching in the field.

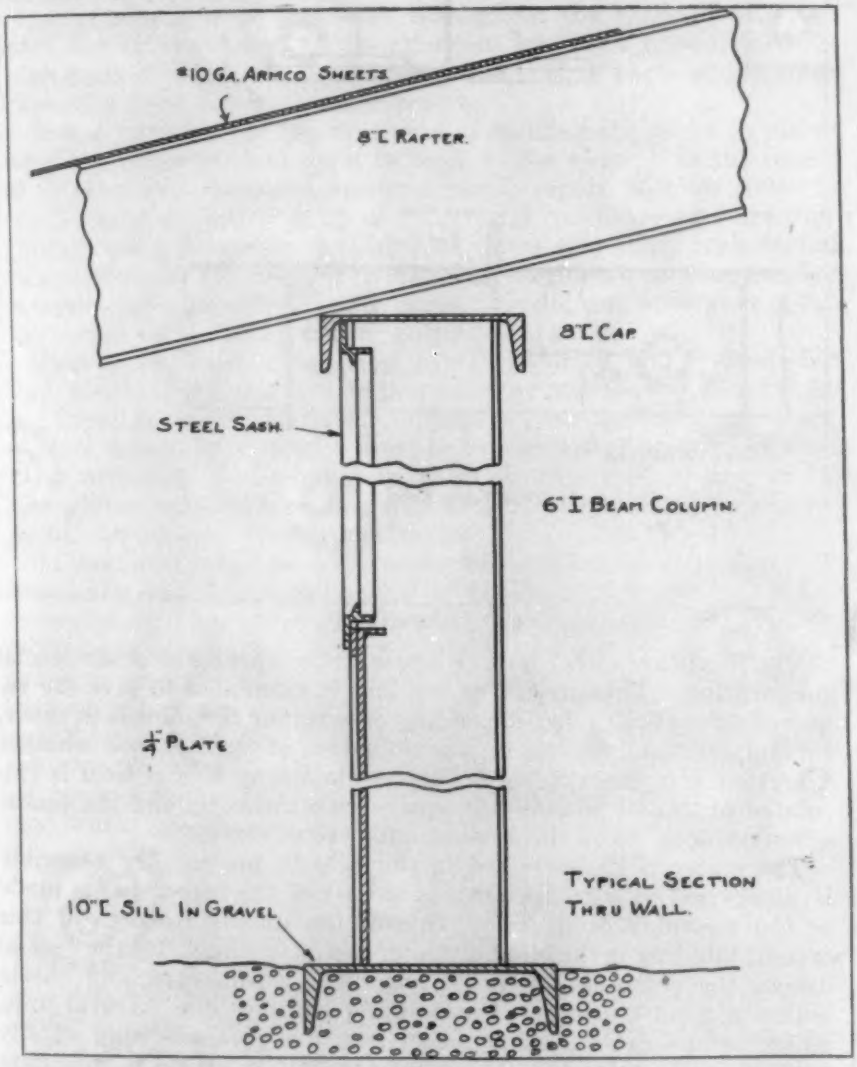

Fig. 1

The erection costs are lower in that it takes only a few seconds to "tack" a member in place, there is no need for "drift pins," and there is less probability of a member not fitting. A welding crew follows immediately after the erection gang and finishes the welding as the work is erected.

Everything, including the steel sash, is welded in place.

The materials used are regular structural shapes, flats, Armco sheets, pipe and steel sash.

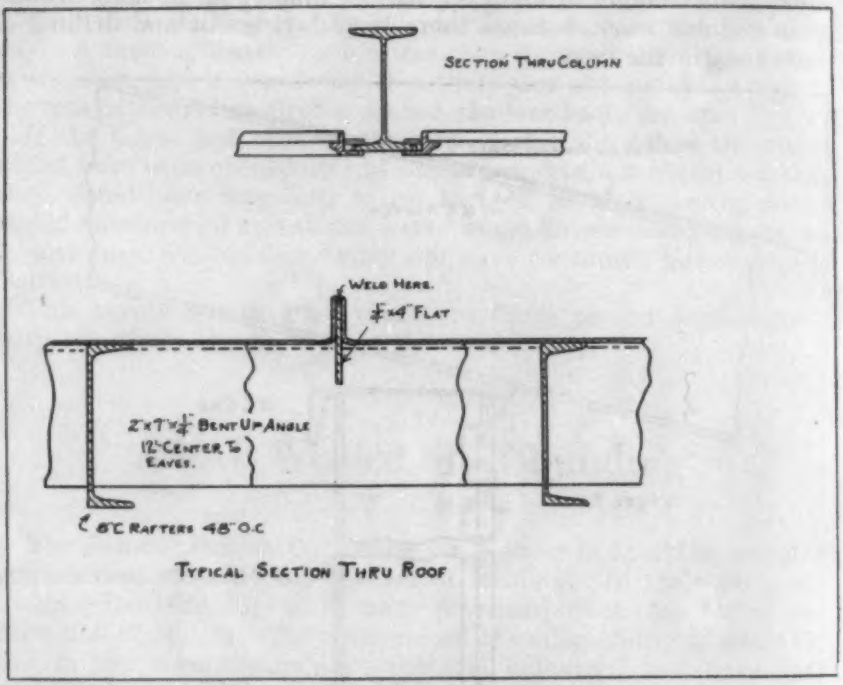

Fig. 2

The joints are either butt or lap, with no scarfing or other special preparation. The amount of welding is calculated to give the required strength of joint, depending on whether the joint is in shear, torsion, tension, bending, or a combination of stresses, and whether vibration may be expected. The tensile strength of a weld is calculated at 28,000 pounds per square inch ultimate, and the factor of safety depends on the amount and type of stress.

The material is assembled in the field in place. The assembly is supervised by a competent engineer and the inspection is made as the assembly progresses. One of the unique features of this type of building is the elimination of heavy footings. By the special design the combination of sill channels, posts, caps and sheets makes a rigid truss, and the building becomes one integral unit, which cannot get out of shape or sag, due to the setting of any part of the foundation. The sides are laid in gravel to minimize corrosion.

The buildings described are additions to one of their factory buildings. The labor and supervision cost on these buildings was about $1.90 per 100 pounds, or $2.20 per 100 cubic feet inclosure. The total cost of the buildings was about $6.55 per 100 pounds, or $7.55 per cubic feet.

Welding as a Method of Fabricating Large Structures*

H. GOLDMARK†, W. SPRARAGEN†† AND W. L. WARNER†††

The various processes of fusion welding have received the especial attention of engineers throughout the world during the past five or six years. This attention has been necessitated by high costs of materials, delays in replacement of parts and in some cases the need for a superior product.

It was natural that the first uses of welding should be in places where no other method could be used, as for example in the repair of broken and damaged machine parts, repair of blow holes in faulty castings, building up of incorrectly machined or worn surfaces. Long delays in getting new parts and high replacement values made it absolutely necessary for engineers to give welding a tryout even though in some cases they did not have very much confidence in welding or were entirely unfamiliar with it.

The applications of welding rapidly doubled and trebled, but this increased use was also accompanied by some evils. Good welding requires proper materials, apparatus, methods and workmen. Certain scientific principles must be recognized if good results are to be obtained. Unfortunately, through ignorance or lack of responsibility some bad welding was done which has caused engineers to be cautious in specifying its use.

In special cases the advantages of welding in producing oil, water and gas-tight construction led to its use as a means of fabricating tanks, pipe lines, vessels and containers of all descriptions. Where methods were standardized remarkable savings and superiority of product were soon apparent as compared with similar riveted structures. Moreover, if properly done a welded joint could be made equal to the strength of the original material, whereas the riveted and caulked joints leaked below 50 per cent of their ultimate tensile strength, and sometimes as low as 25 per cent.

Welding versus Riveting in Structural Work

Unless, of course, it is possible to show advantages in using welding as compared with riveting in the fabrication of large structures, it is hardly to be expected that engineers and builders will abandon their present methods of riveting which have been found to give satisfactory results in service.

The many advantages of welding are well known to those who have been intimately associated with welding developments during the past few years. These people are, therefore, surprised that

*To be presented at the Fall Meeting, A. W. S., Cleveland, Oct., 1924.
†Consulting Engineer.
††Secretary, American Bureau of Welding.
†††Industrial Engineering Department, General Electric Co.

other engineers do not understand these advantages and possibilities. In some cases where the welding process is understood, there is considerable apprehension at the thought of abandoning present old and tried methods for something new. Also the question of scrapping machinery and equipment which have required large outlays of money is of considerable importance to the executive.

The two methods are radically different as to manufacturing processes. For example, the following steps are necessary in riveting a building or bridge:

1. Design.
2. Making the drawings.
3. Making templets.
4. Marking steel.
5. Punching or drilling holes.
6. Assembling.
7. Riveting.
8. Painting in the shop.
9. Erection.
10. Painting in the field.

Let us compare the steps involved in erecting the same bridge or building by welding, in which case they would be:

1. Design.
2. Making the drawings. (Much simpler as compared to riveting where each rivet must be shown).
3. Preparing material to be welded. (In some instances this requires beveling of plates, in others removal of rust, and in still others no preparation at all).
4. Erection.
5. Painting in the field.

These differences in methods of fabricating result in several inherent advantages in favor of the welding process.

Saving in Weights

Data from existing examples of this type of construction show that a saving of from 15 to 25 per cent in weight can be secured. The welded joint may easily be made as strong as the parts themselves while the corresponding riveted joint is rarely equal to 75 per cent of the strength of the parts. Moreover this saving in weight and increased efficiency can be secured by proper welding, and even the weight and cost of the rivets is very little less than the weight and cost of the welding wire.

The elastic features of the welding process commend it to this class of work especially. Sometimes the welded joint may necessarily be so situated that the weld as laid out by the draughtsman cannot be completely made, due to interference by other members, etc. In that case the weld may be shifted somewhat or an extra plate added without any appreciable delay or increased weight and cost. With a riveted member considerable time and cost

would be necessitated in preparing an additional gusset plate and riveting it.

Simpler Drawings Required

With the riveted type of steel structure each rivet must be clearly indicated on the drawings, both with regard to size and position. Considerable attention must be given to laying out the joints so that the members will fit snugly together and yet allow proper clearance for driving rivets. Very often the expense of making these drawings is an appreciable part of the total cost. The drawings for a welded structure are much simpler as all rivets are eliminated and there are fewer details at the joints.

3. *Elimination of Certain Steps.* The following steps necessary in the shop for the riveted construction are eliminated when the welding processes are used: making templets, marking steel, punching or drilling holes and painting.

4. *Accurate Alignment Not Necessary.* In welding, parts need not be aligned as accurately as in riveting. In the latter case it is frequently found that because of inaccuracies of workmanship, holes do not come exactly opposite, but by driving a drift pin the holes are more nearly brought in line and then reamed to get a smoother and larger hole before a rivet is driven. The piece to be riveted must be moved around in order to bring the rivet in the proper position in the riveting machine, or else the riveter is portable for use on heavy work and is so arranged that it could be moved about as the rivets are driven.

In outside construction the alignment of rivet holes and the driving of rivets is a slower and more tedious job. Perfect alignment is necessary before the rivets can be driven. With welded construction the members can be fitted in place and considerable freedom is allowed for making joints. If the piece being placed is too long an oxy-acetylene torch may be brought into play and the joint made. Often times members and plates may be cut to size with the oxy-acetylene torch and the parts welded together. The freedom allowed by the use of the process is one great advantage.

5. *Elimination of Noise.* The elimination of the noise of riveting may not seem of any consequence to the contractor, but undoubtedly he would be happier if his job could be quieter. The elimination of this noise is of the greatest importance to the public, especially in the big cities. Anyone who has been for a time in the proximity of a job where riveting was being done can appreciate the value of eliminating the noise and racket.

6. *Saving in Freight and Handling.* Because of the lesser weight of the material involved, freight and cartage charges will be considerably less.

7. *Superiority of Product.* Where oil, water or gas tightness is required the superiority of a welded product which is tight up to its ultimate strength commends itself as compared to a riveted structure which is only tight up to 50 per cent of its ultimate strength.

"Once tight always tight." That's the secret of good welding. In any steel structure there occurs inevitably a certain amount of movement due to impact of wind, expansion and contraction, etc. Riveted joints sometimes loosen slightly due to these forces, and in time unless repaired there will be trouble. A welded joint is solid and no movement can take place. The various members become in reality parts of each other and together make one integral whole.

8. *Economies.* A combination of all these factors makes it possible with the use of welding to produce a structure which is cheaper and better than the ones constructed by riveting. The

Fig. 1—Method Employed to Measure Modulus of Elasticity in English Tests

designing is more easily and quickly done. The only shop work required is that for cutting gusset plates and members to the proper size. Assembly and erection are more easily and quickly done and there are few possibilities of delay caused by errors in laying out. The savings may amount to from 10 to 25 per cent of the total cost.

The Use of Welding As a Substitute Method for Fabrication

Before welding would be specified, structural engineers must be convinced that it is entirely safe for the purpose at hand.

Two kinds of tests are needed. Results obtained (1) in service from structures fabricated by the welding processes and (2) from laboratory tests where stresses will be introduced in specimens of the nature most likely to be met in service.

In England, on behalf of Lloyd's Register of Shipping, a number of large size specimens were welded. Specimens were machined to give a vee groove having a 60° opening the full depth of the

plate. The welding was done in a horizontal position from the upper surface. It was found that the welding had completely penetrated the plates, no welding on the reverse side being necessary. The excess of weld was not trimmed off, except in a few cases, but was left rough as finished by the workmen, the weld being slightly above the surface of the plate to about the same extent as the point of an ordinary countersunk rivet.

Results of English Tests

NOTE: These English tests are so important that the conclusions derived from these tests are reproduced below. Complete

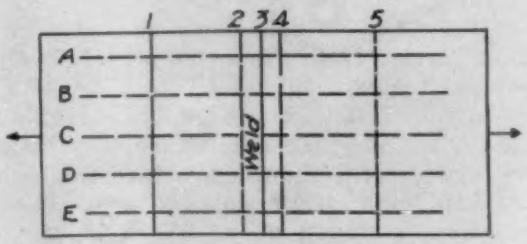

Fig. 2—Sketch Showing Positions of Readings in Measuring Modulus of Elasticity

test results and description of specimens are included in a paper presented by Mr. W. S. Abell on application of Electric Welding to Large Structures, published before the Institution of Civil Engineers.—1921.

1. *Modulus of Elasticity and Approximate Elastic Limit*

(a) In the welded plate the extensions in the region of the weld are sensibly the same as for more distant portions of the unwelded plate. (See Figs. 1 and 2.)

(b) With small welded specimens containing an appreciable proportion of welded material in the cross-sectional area, the relation between extension and stress is practically the same, up to the elastic limit, as for similar unwelded material.

(c) The elastic limit (or the limiting stress beyond which extension is not approximately directly proportional to stress) appears to be slightly higher in welded than in unwelded material.

(d) The modulus of elasticity of a small test-piece, entirely composed of material of the weld, was about 11,700 tons per square inch, as compared with about 13,500 tons for mild steel and about 12,500 tons for wrought iron.

2. *Ultimate Strength and Ultimate Elongation.*

(a) The ultimate strength of welded material with small specimens was more than 100 per cent of the strength of the unwelded steel plate for thicknesses of ½ inch, and averaged 90 per cent for plates ¾ and 1 inch in thickness.

(b) Up to the point of fracture the extensions of the welded

specimens are not sensibly different from those of similar unwelded material.

(c) At stresses greater than the elastic limit the welded material is less ductile than mild steel, and the ultimate elongation of a welded specimen, when measured on a length of 8 inches, averages only about 10 per cent, as compared with 25 to 30 per cent for mild steel.

3. *Strength of Welds (Large Specimens)*

(a) Butt Welds have a tensile strength varying from 90 to 95 per cent of the tensile strength of the unwelded plate.

(b) Lap Welds.

(1) With full fillets on both edges the ultimate strength in tension varies from 70 to 80 per cent of that of the unwelded material.

(2) With a full fillet on one edge and a single run of weld on the other edge the results are very little inferior to those where a full fillet is provided for both edges.

(c) Riveted Lap Joints.—For plates of about ½-inch in thickness, the specimens averaged about 65 to 70 per cent of the strength of the unperforated plate.

4. *Alternating Stresses*

(a) Rotating Specimens (round bar).

(1) Unwelded turned bars will withstand a very large number of repetitions of stress (exceeding, say, five millions) when the range of stress is not greater than from 10½ tons per square inch tension to 10½ tons per square inch compression.

(2) Welded bars similarly tested will fail at about the same number of repetitions when the range of stress does not exceed ± 6½ tons per square inch.

(b) Stationary Test Pieces (flat plate).

(1) Butt-Welded specimens will withstand for a large number of repetitions about 70 per cent of the stress which can be borne by an unwelded plate.

(2) Lap-welded* plates can endure for a large number of repetitions about 60 per cent of the stress which can be withstood by a lap-riveted specimen.

5. *Minor Tests*

(a) Welded specimens are not capable of being bent (without fracture) over the prescribed radius to more than about 80 deg. with ¼-in. plate, reducing to some 20 deg. where the thickness

*NOTE—The conclusions drawn as to the relative merits of lap welded and lap riveted seams in resisting alternating stresses are in the opinion of the authors not justified. It seems that the British investigators used a type of machine which gave a certain deflection for a particular test. It does not necessarily follow, however, that the forces necessary to cause this deflection would be the same for the lap welded and the lap riveted joints. In fact it is well known that the welded joints are the stiffer of the two and therefore a considerable additional force must have been required to cause the same deflection in the welded joint. This is particularly true after there was some giving in the rivets.

is 1 in. Unwelded material under the same conditions can be bent through 180 deg.

(b) Welded plates can withstand impact with a considerable degree of success; a 1-in. plate of dimensions already quoted sustained two successive blows of 4 cwt. dropped through 12 ft.,

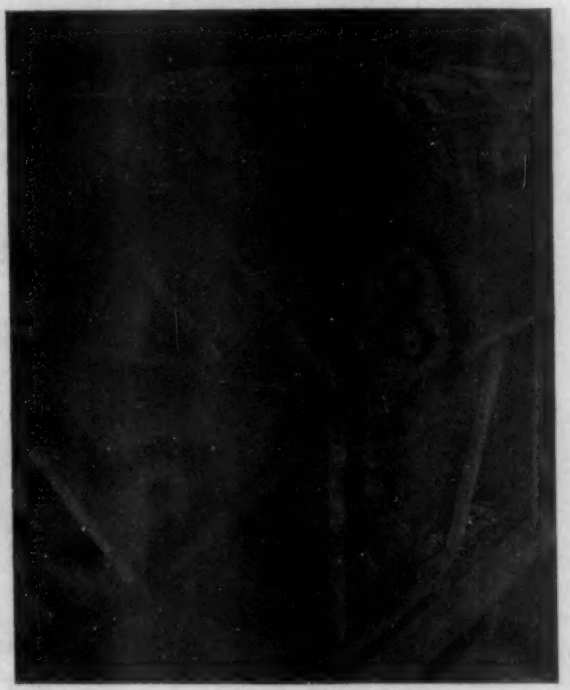

Fig. 3—Electrically Welded Box Constructed for Experimental Purposes for the Electric Welding Committee of the Emergency Fleet Corporation. Box Under a Hydrostatic Pressure Test of 40 Lb. Per Sq. In. Note Bulging of Plates

giving a deflection of 12 in. on a length of about 4 ft. 6 in., without any signs of fracture in the weld.

6. *Chemical and Microscopic Analysis*

(a) Chemical Analysis.
  (1) The electrode was practically identical with mild steel, but there was a higher percentage of silicon.
  (2) The material of the weld after deposition was ascertained to be practically pure iron, the various other contents being carbon 0.03, silicon 0.02, phosphorus 0.02 and manganese 0.04 per cent respectively.

(b) Microscopic Examination.
  (1) The material of the weld is practically pure iron.
  (2) The local influence of heat does not appear to affect largely the surrounding material, the structure not being

much disturbed at about 1/16-in. from the edge of the weld. The amount of disturbance is still less in thin plates.

(3) The weld bears little evidence, if any, of the occurrence of oxidation.

(4) With welds made as for these experiments, i. e., with flat horizontal welding, a sound junction is obtained between the plates and the welding material.

Welded Steel Box for Emergency Fleet Corporation

The following interesting results were obtained on a large steel box, 12 ft. x 9 ft. x 10 ft., made of ½-in. tank steel plate for the information of the Electric Welding Committee of the Emergency Fleet Corporation.

The principal data to be obtained from the construction and testing of this box were:

(1) Could a structure of this character be built close to drawing dimensions and without excessive distortion of the plates and parts?

(2) Would the structure be strong and capable of withstanding severe shocks and distortions without serious ruptures?

(3) What would be the detail costs and time required to build such a structure?

The entire box was electrically arc welded, no rivets being used in its construction. The welded joints are neat and attractive in appearance, and the substantial character of the work is revealed in Fig. 3, which is a photograph taken during the severe tests imposed upon the box. The box was subjected to alternate applications of 15-lb. internal hydrostatic pressure and 22-in. vacuum more than 200 times and did not develop any serious leaks or failures in the welds. These results show that the condition (2) is satisfied to a considerable degree.

The cost of work done on the box was as follows:

Cost of welding	$151.28
Fabricating and assembling	157.94
Preliminary testing	50.00
Welding wire	30.00
Material	651.30
Total cost	$1,040.52

Tests on Arc Welded Roof Truss

Mr. H. L. Unland in a paper presented before the Society of Engineers of Eastern Pennsylvania in 1921 describes a test which was made on the roof trusses for a factory building in Brooklyn by the Bureau of Buildings of the City of New York in 1920. See Fig. 4. This building was completely arc welded as an experiment by the Electric Welding Company of America.

The trusses are of the "Fan" type of design and all members are electrically welded together, no bolts or rivets being used. See Figs. 5 and 6.

The object of the test was to demonstrate whether electric welding was a suitable method of uniting structural steel members and

Fig. 4. Roof Trusses Electrically Welded Throughout for Factory Building Being Tested by Department of Buildings, City of New York

also the reliability of the arc welded parts as compared with riveting. As the angle of the truss or roof was greater than 20 deg., the live load prescribed by the Building Code was 30 lb. per square foot of horizontal plane. As the trusses were intended to be set on 30 ft. centers the roof area to be supported was 800 sq. ft. By doubling the live load, the stress in the members of the truss would closely approach the elastic limit of the material.

The load applied was 60 lb. to the square foot or 48,000 lb. per truss. As it was necessary to set up two (2) trusses to balance the load, this load was doubled or 96,000 lb. total was used. The trusses were set up on H section columns laid under the ends of the trusses in a horizontal position on the top of a plank to distribute the load over considerable area.

The roof purlins were 3 in. x 10 in. spruce and were doubled to carry the load. The planking under the load was also of the same material. The two loads were concentrated over an area of about 5 ft. in width at each truss. The load consisted of roofing gravel in bags which averaged 55 lb. to the bag. These bags were piled in tiers. Readings were taken at different increments of the loading for the deflection in the truss or members, and as a whole, these were checked each time from a bench

mark. The instrument used was an engineer's Y-level and target rod divided in feet and tenths.

It is interesting to note that the maximum actual deflection of any part of the truss under full load was 9/16 in. at the center of the span. The load was allowed to remain on the trusses for 48

Fig. 5—Side View of Supporting Bracket for Crane Runway Electrically Welded to Column of Structural Steel Work

hours with no increase of deflection and then it was totally removed and readings taken. These latter readings showed that all points in the truss had returned to their original position leaving no permanent deflection with the exception of the center which showed a deflection of 1/16 in.

The report goes on to state further "From the above data, it is evident that electric welding is a dependable method of uniting structural members and is stiffer than riveting, if the work is properly performed.

Prior to the test as above, we had a sample of welding on a lap weld of 1¼ in. x ⅜ in. bars, the ends being lapped 1¾ in. and welded across the edges. This weld was put in the machine in direct tension and developed the full strength of the bar. The break occurred in the bar 3 in. above the weld and developed a strength equal to 60,000 lb. per square inch without affecting the weld. These welds when cut across showed no line or markation between the weld metal and the original bar metal.

Another specimen consisted of two (2) angles (2 in. x 3 in. x ⅜ in.) set at right angles and lap welded at the intersection, with the 3-in. legs vertical. This specimen, which was set in

the testing machine so that there was a horizontal lever arm of 8 in. from the center of pressure to the center of the weld at the intersection, developed a beam load of 11,375 lb. at the weld or a torsional stress of 91,000 lb. at the weld with no apparent distress to the weld, the angles buckling to such an extent that they failed to resist pressure.

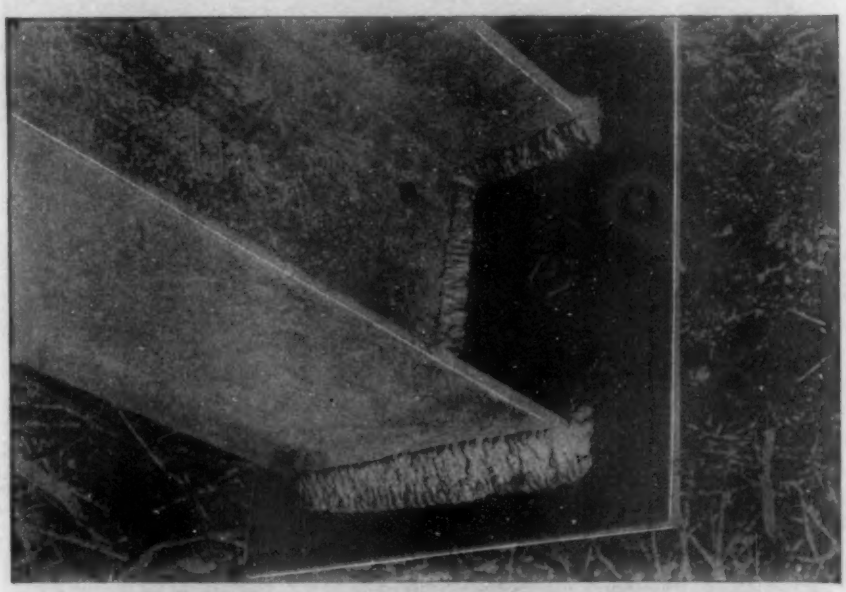

Fig. 6—Roof Trusses Electrically Welded Throughout for Factory Buildings Being Tested by Department of Buildings, City of New York

Mr. Unland further remarks: "This structure was intended to carry very heavy loads and from the illustrations, showing the welded joints (Figs. 4, 5 and 6), entire success would be expected. Very little information is available as to the cost of completing this structure, but the designer and constructor, Mr. H. B. Payne, is certain that, with the experience gained on this structure, similar structures could be erected at a much lower cost than if riveted construction were used.

"While it is probable that with proper design and under competent supervision, skilled welders could successfully put up welded structures of any size, we must remember that there is little experience as to the design of the joints most suitable for replacing riveted joints. Slow progress in making this change is greatly to be desired. Experience with smaller structures will furnish a safe guide in trying out the larger ones."

Shearing Strength of Welds

Practically all riveted joints depend for their strength upon the shearing value of rivets or on the bearing of rivets upon the plates connected. If welding is to be substituted for riveting in

many places the deposited metal at the weld will be subject to shear and therefore considerable data is needed on this subject. Some tests were made by Mr. E. S. Humphreys at Union College and the results given in a paper printed in May 25, 1922, issue of

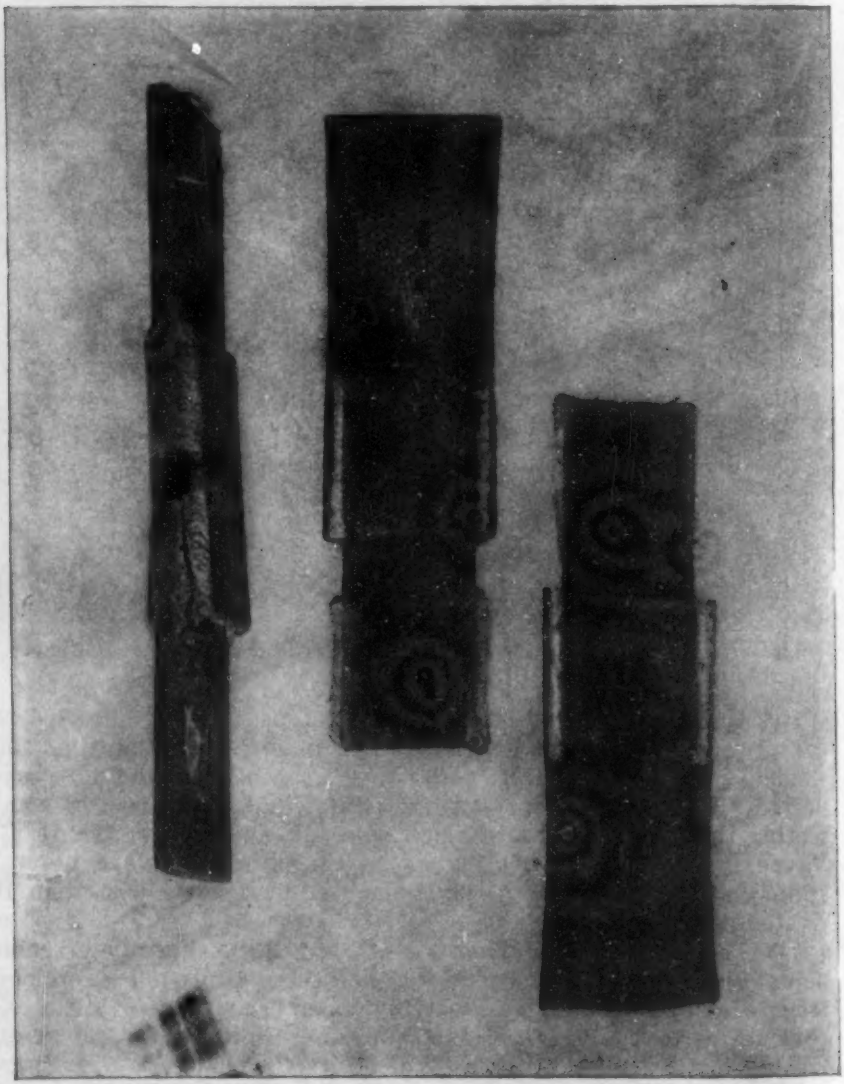

Fig. 7—Two Test Specimens After Being Tested in Shear. Middle and Right Pieces are Two Parts of One Broken Specimen. The Left Specimen Shows the Shearing of the Bead

Iron Age. The type of specimens used is illustrated in Fig. 7 which shows two test specimens after being submitted to a tensile test to fracture. Each specimen consisted of two plates joined

together by two splice bars in such a manner that deposited metals or beads run parallel to the length of the plates and therefore parallel to the tensile pull exerted upon these plates with the result that the beads are subjected to shear. The shearing strength of the deposited metal from a commercial bare electrode was found by Mr. Humphreys to be about 36,000 lb. per square inch. From these tests Professor McKibben of Union College has arrived at certain figures which give the maximum safe load in pounds per lineal inch of bead which various sizes of weld beads will safely carry with a factor of safety of four. Full information as to the calculations used by Prof. McKibben in designing a welded truss is given in Appendix "A."

Joints Specifically Designed for Welding

Up to the present time most welded structures have not been carefully proportioned with proper regard for stresses to be carried and the strength of the parts necessary to carry them. Little is known of safe methods of design for steel structures although there are several instances where steel works have been erected without rivets, the joints having been put togther by arc welding. In most cases this work has been done by designing a structure for riveting and then welding the joints wherever possible with the electric arc. In this manner welded structures have been built which are considerably heavier and stronger than is necessary to carry the required loading.

In a report to the American Bureau of Welding covering the "Application of Arc Welding to Ship Construction," Mr. E. H. Ewertz states that it is his belief that substituting welding for rivets in a structure designed for using either method is wrong as a basic principle. The results derived from welding in such a method are at least partially defeated. All of the structural shapes such as angle bars, tee bars, zee bars, etc., were designed primarily for convenience in riveting. One flange of an angle bar is used simply as a means of fastening the other flange in its proper position. It is only the outstanding flange that gives stiffness and strength to the plate construction and the flange used for fastening by rivets is valuable only for furnishing the place for the rivets and does not add to the strength of the structure.

With this in mind, Mr. Ewertz designed an arc welded ship in which all flanges needed in the riveted structure for fastening are omitted and in place of angles or other shapes, plates or flat bars are used. To produce reinforcement in many places, flanged plates are used, but in such cases the flange on the plate performs the service of a stiffener. (See Fig. 8.)

Another important item which the structural engineer who considers welding for fabricating should have in mind is the design of parts in such a way that most of the welding can be performed in the shop and overhead welding eliminated as much as possible.

Mr. Ewertz goes on further to state that in a ship designed for all electric welding, estimates show a saving in weight of structural steel material of over 25 per cent as compared with a similar design for a riveted ship. The hours of labor for hull construction showed a reduction of over 20 per cent. Modified designs or designs where either riveting or welding can be used while they clearly indicate a saving, show a saving that is naturally proportionately lower to that obtained in a ship designed for all electric welding.

Fig. 8—Model of Ewertz Type of Electric Arc Welded Vessel Carrying 400 Per Cent Overload

These same fundamental facts were recognized by the General Boilers Co. in the construction of their factory building which is described in detail elsewhere in this Journal.

In Appendix "B" one of the authors (Mr. W. L. Warner) compares in detail a riveted truss with one where welding has been substituted.

The structural engineer is inclined to look with suspicion on a single weld which carries enormous loads and where failure might result in damage to life or property. While he knows that riveting is not altogether a safe proposition as indicated elsewhere in this report, nevertheless he feels that because there are so many of them that even if 15 per cent were bad the structure would still be safe because of the factor of safety employed in the design.

These engineers feel, moreover, that while some welded parts

are equal to the strength of the original material, nevertheless it is impossible in some instances to detect a bad weld which may have only 50 per cent of the strength of the original material. Of course the welding experts will argue that the solution is proper welding inspection and this subject is treated elsewhere. However, if possible welding parts should be so designed that there will be a large number of small welds to carry the load instead of one large weld. The same arguments would then hold true as in the case of riveting.

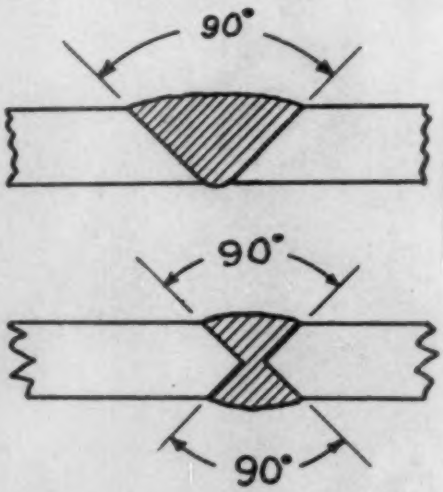

Fig. 9—Upper Figure Is Single Vee Type of Joint. Lower Figure Double Vee Type

In the past the structural engineers who were not familiar with welding have been inclined to take the cross sectional area of a weld and allow so many pounds per square inch as the tensile strength or shearing stress of this particular weld. There are many important variables which make such a procedure dangerous, such as for example design of joint, chemical composition of parts to be welded, type of electrode used. This can be best illustrated by comparing the two simple types of joints shown in Fig. 9. In one figure there is shown a single vee double beveled joint; in the other a double vee double beveled joint. The cross section of deposited weld metal is the same and yet a number of tests in structures such as tanks have shown that the double vee joint is from 25 to 50 per cent stronger than the single vee joint. This difference can be ascribed to the fact that (1) it is harder to make a thoroughly sound fused joint with the single vee type, particular at the bottom of the vee and (2) that because of the unsymmetrical section of the single vee a bending strain is thrown on the deposited metal (it must be remembered that the deposited metal has different physical characteristics from the original base

metal). From an economical viewpoint it so happens that it costs less to make a double vee than it does a single vee joint.

It should also be remembered that the physical properties of the deposited metal depends not only upon the type of electrode

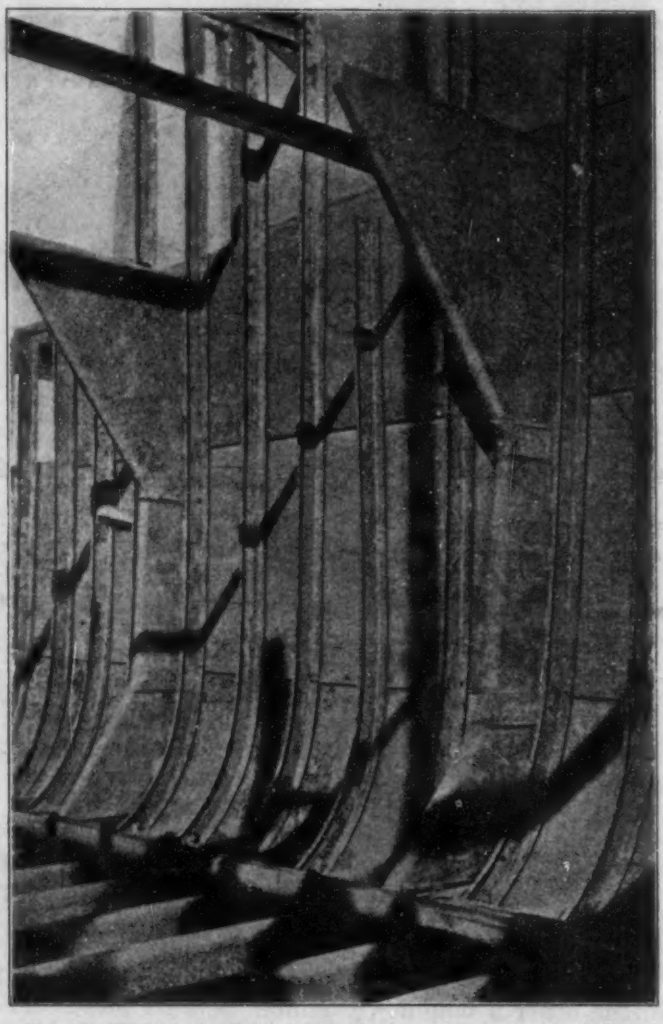

Fig. 10—Electrically Welded Ship Fullagar, Floor Plates, Frames and Plating

used but also on the physical and chemical properties of the base metal.

Another important factor which must be taken into account is the fact that in some instances joints designed for riveting do not make it possible to secure good welding. Factors such as position of welding, heat conductivity of the edges to be joined, etc., are some of the reasons that may be cited.

Large office buildings are usually of a steel cage type. This type of construction lends itself particularly to welding as the safety of a building does not depend upon any single weld.

Lockgates and Caissons

Among structures especially well adapted for the use of welding, lockgates, caissons and similar works employed by hydraulic engineers may be mentioned.

Structures of this kind are intermediate in character between ship construction and bridge work. A large part of the material

Fig. 11—Electrically Welded Coaster Fullagar, Built by Cammell-Laird Company, Ltd., Using Flux-Covered Electrodes

used in them consists of steel plates of varying thicknesses, designed to support water pressure, but there are also heavy girders, vertical and horizontal bracing frames, and decks forming the skeleton of the structures.

In order to obtain water tightness, it has been necessary in the past to use a large number of rivets, quite closely spaced and to caulk the edges of all the outer plates. In the case of most of these rivets, the direct stress is quite small, although in some parts of the gate frames there are a relatively small number of rivets under rather heavy stress.

It is believed that a careful analysis of structures of this kind would show that, by making some changes in the design, welding might with advantage be substituted for riveting and caulking in a large part of the work, although it might best to use rivets for certain connections.

An example of structures of this kind may be found in the large lockgates used on modern canals.

On the Panama Canal, for instance, there are in all 94 mitering lockgate leaves, each weighing on the average about 300 tons. The length of the leaf is 65 ft., its thickness 7 ft., while the height

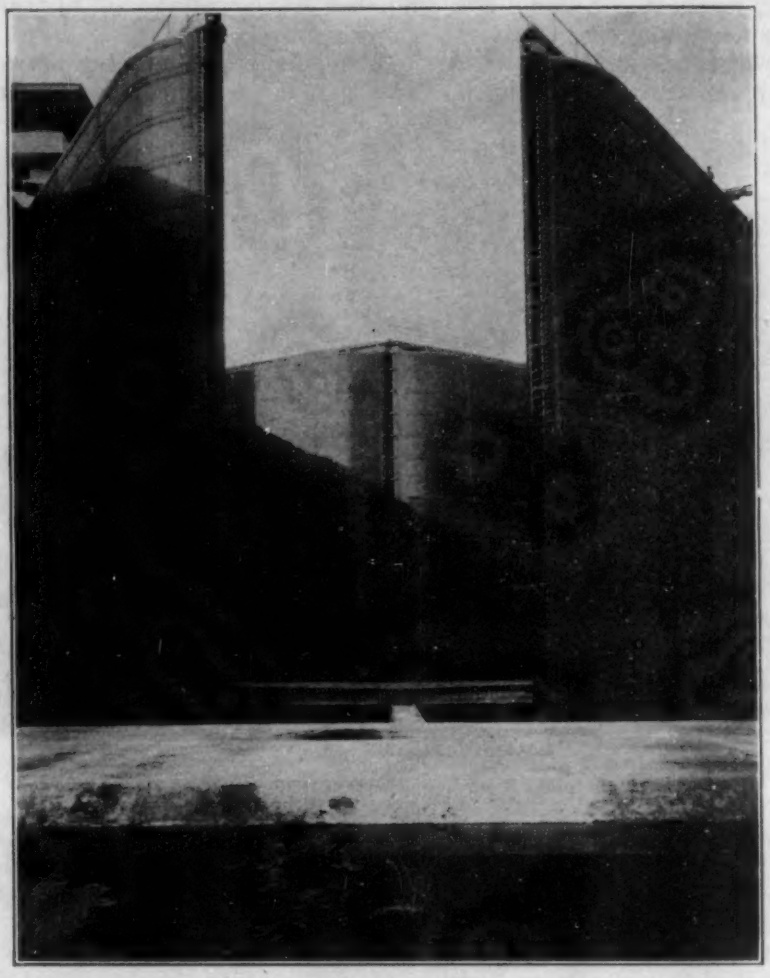

Fig. 12—Panama Lock Gate. Typical Structure where Welding Might be Substituted for Riveting

varies from 45 to 82 ft. The framework consists of longitudinal horizontal girders, spaced 3 ft. 8 in. to 5 ft. apart with vertical frames 7 to 8 ft. between centers, built in between the horizontals and forming a complete vertical bracing for the gate frame. Both faces of the leaves are covered with steel plating. (Fig. 12.)

The horizontal girders and the individual bracing frames were shop built, but over 6,500,000 rivets were driven in the field, for

connecting the bracing and attaching the outer skin. It was also necessary to do a large amount of caulking.

The driving of this enormous number of rivets was a rather serious undertaking. In order to insure water tightness it was

Fig. 13—Launching of the Welded Vessel Ac 1320

thought best to punch the rivet holes quite small in the shop (11/16 in. diameter for 7/8 in. and 1 in. rivets) and then ream them in the field.

It proved difficult to do this without introducing chips into the space between the plates, which interfered with getting tight rivets.

It was also hard to get a sufficient number of experienced riveters, since as many as 165 gangs were required at one time. The number of rivets rejected on inspection was very great, which increased the cost to the contractors and led ultimately to a large claim against the Government, met in part by an additional Congressional appropriation.

It is believed that in the case of a large proportion of both the shop and field rivets, welded joints could have been substituted and the troublesome caulking of the plates could also have been eliminated. It would probably be necessary to modify the design in some respects, but there seems to be no reason for doubting that with due care a gate of equal strength could be built at decidedly lower cost.

Cost Data

No reliable figures are available as to the comparative costs of welded structures and ones fabricated by riveting. In the shipbuilding field, however, some such data has been compiled which are available. In a paper read before the Society of Engineers and Shipbuilders in Scotland Major James Caldwell brings out that in the construction of a cross channel barge the following savings were effected—245 man hours and 1000 lb. of metal.

The comparative costs of building this barge are $1,462.86 for the welded construction as against $1,892.48 for the riveted. It

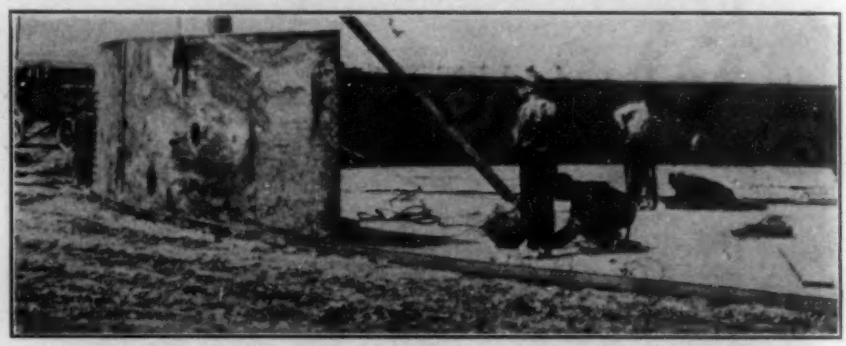

Fig. 14—Welding Bottom of an 80,000 Barrel Tank. Part of the First Shell Ring Is in Place. Two Gas Engine Driven Generator Arc Welding Sets in Action at Left

should be noted that the design was not particularly adapted for welding. In the report prepared by Mr. Ewertz (previously referred to) some comparative costs for riveting versus welding are worked out in a number of operations. A summary of these, including overhead costs, are as follows:

Name of Fitting	Number Pieces	Rivets Per Piece	Inches of Welding Per Rivet	Total Riveting Cost	Total Welding Cost	Saving by Welding
Cargo batten clips	98	2	10	$97.32	$127.61	—31
Large awning pads	20	2	9	44.96	21.81	51.5
Small awning pads	24	2	4.75	44.13	20.61	53
Triangular hand rail stanchions	48	3	6	126.36	56.79	55
Vertical hand rail stanchions	115	2	9	142.92	137.72	4
Pipe hangers—F. W. line	57	2	4	118.26	70.66	40.4
Pipe hangers, drain and fuel	92	2	8	191.10	141.71	26
Clips—pump room, pipe hangers	6	4	9	14.70	13.24	9.8
Clips, pump room gratings	24	2	8.5	42.77	35.47	17
Bounding angle butts	50	..	..	329.05	71.68	78

Several years ago an attempt was made by W. Spraragen to compile basic figures for welding costs which would be applicable to almost any form of welding, including applications in the structural field. This paper was published in the June, 1920, issue of the *Welding Engineer*. It showed that the speed of "arc" welding is affected by a number of factors, some of the most important of which were type of joints, preparation of welding edges, position of welding, amount of current used, diameter of electrode, polarity and length of arc. In order to make the figures universally ap-

plicable the author expresses the speed of arc welding in pounds of metal deposited per hour. To compute the time for welding any particular job it is only necessary to divide the pounds of metal that can be deposited per hour by the weight of added metal that must be used to complete the joint. The weight of this added metal is, of course, readily computed from the volume it is expected to occupy. In computing this volume the author states that it is advisable to add 10 to 20 per cent to allow for the fact that the added material rises above straight line surfaces and is consequently of somewhat larger cross section.

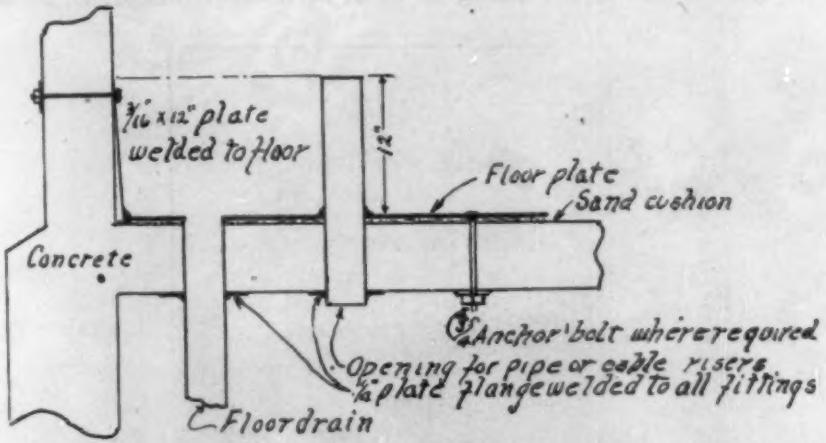

Fig. 15—Details of an all Welded Floor, Constructed by the Hershey Chocolate Co.

The average result of a vast amount of data shows the operator can deposit 1.8 lb. of metal per hour. This rate depends largely upon whether the work is done out in the open or in a special place provided in the shop. For outside work the operator may not average more than 1.4 lb. per hour. The loss in speed for outside work is brought about largely by the cooling action of the air and also somewhat by the added inconvenience to the operator. The value of pounds per hour given above is based on the assumption that the work has been lined up and is ready for welding.

In computing costs it is also important to know the amount of electrode material that is necessary to complete a good job. From experience it has been found that an average of 70 per cent of the weight of bare iron wire is deposited in the weld, the rest being either vaporized or wasted as "short ends." From these figures and knowing the volume of metal needed to complete any joint it is, of course, quite easy to determine the total weight of electrodes needed.

However, in order to make estimates of erecting structures by welding, it will be necessary to compute accurate figures on the cost of welding a particular type of joint, including preparation of work, amount of power needed and overhead expenses. It will not be

then necessary to resort to these basic figures as the computations will be much simpler.

One of the factors which will undoubtedly influence the cost of welding will be the applications of the gas-cutting torch. Cutting by the oxy-acetylene flame has been so well standardized that machine-like jobs can be obtained at a fraction of the cost of cutting by mechanical means.

Existing Welded Structures

In a paper printed in the Journal of the American Welding Society entitled "Arc Welding of Steel Structures," Prof. F. P. Mc-

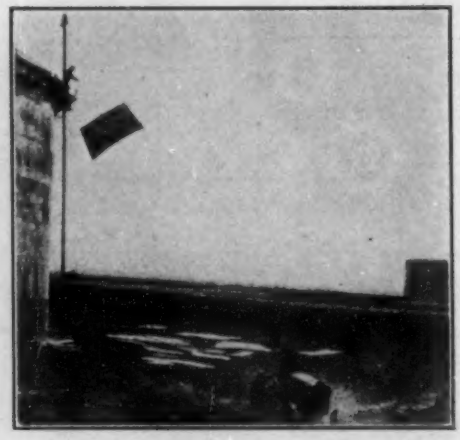

Fig. 16—Raising the Roof Sheets for an all Welded Roof for a Large Storage Tank

Kibben describes and illustrates a number of existing structures which are quite varied in nature. These include the following:

1. Stables for the Olympia Horse Show, England, 1920. The building covers an area of over 9000 sq. ft., the span of the roof trusses being 14 ft. All steel parts were cut to length and delivered to the site of the building ready for erection, where two welders and four laborers obtained an output of ten completed trusses per day.

2. Mill building at Brixton, England. Mill building has a sawtooth roof covering 22,000 sq. ft., having roof trusses of three spans each of 19 ft. and supported on "H" section columns. Truss members were cut to proper lengths and then placed in jigs where they were held in position and the joints welded. The truss was then removed and erected.

3. Cross Channel Barge for use between England and France. Length 125 ft. 9 in., breadth 16 ft. 4 in., molded depth 7 ft. 9 in., shell plating ¼ in. and 5/16 in. lapped and joggled. The plates were assembled by means of a few service bolts, which after the welding of the joints were withdrawn and the holes closed by means

of arc welding. Several barges of this type have been built in England.

4. The 500-ton coasting ship *Fullagar*, launched Feb. 5, 1920, length 150 ft. (Figs. 10 and 11)

5. Transmission line towers have been constructed in Belgium having a height of 72 ft., carrying 7 wires on 525-ft. spans. All parts were electrically welded except for convenience in transportation the upper and lower sections were spliced together in the field.

6. At Fitzroy the Metropolitan Gas Company constructed a gas-

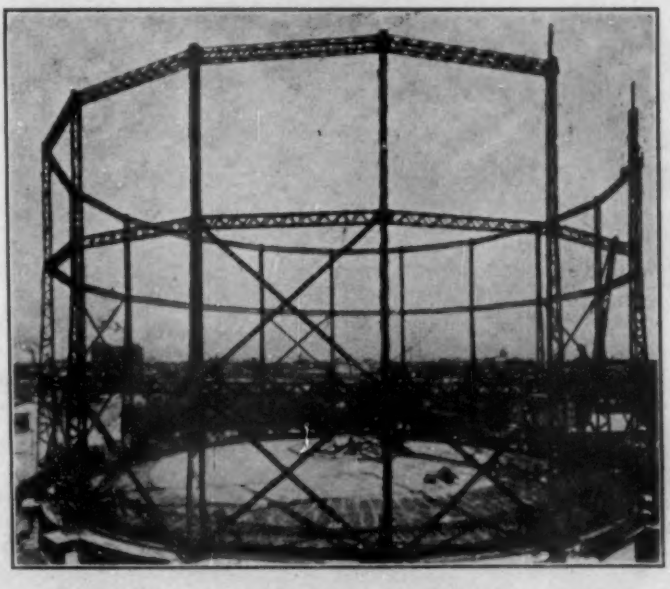

Fig. 17—Completing the Third Bay of a 2,000,000 Ft. Gas Holder at Melbourne, Australia. Note the Welded Guide Carriages

holder of 2,000,000 cu. ft. capacity which, except for the assembly rivets, is electrically welded. The diameter of the tank is 150 ft. and has four 35-ft. lifts. The latticed guide columns are 130 ft. high. Still another tank 200 ft. in diameter was constructed in Melbourne, Australia. (Figs. 17 and 18)

7. Large boom for a derrick, approximately 90 ft. long. Except for a connection at the middle of the boom, all joints are made by arc welding.

8. Gondola freight car. The American Car and Foundry Company designed a Gondola freight car of 50 tons capacity in which electric spot welding was used in the superstructure.

9. Transformer tower, General Electric Company constructed at Schenectady plant a steel frame 40 ft. wide x 40 ft. long and 40 ft. high to serve as a transformer tower, all parts being arc welded. The structure contains 34,339 lb. of structural steel.

10. Steel bridge. A steel bridge connecting two buildings was constructed by the General Electric Co. by means of electric welding, only a few rivets being used at the connection of one of the buildings.

Other Examples of Welding Structures

An All-Welded Steel Floor. An all-welded steel floor was constructed by the Hershey Chocolate Company, 64 ft. x 24 ft., for

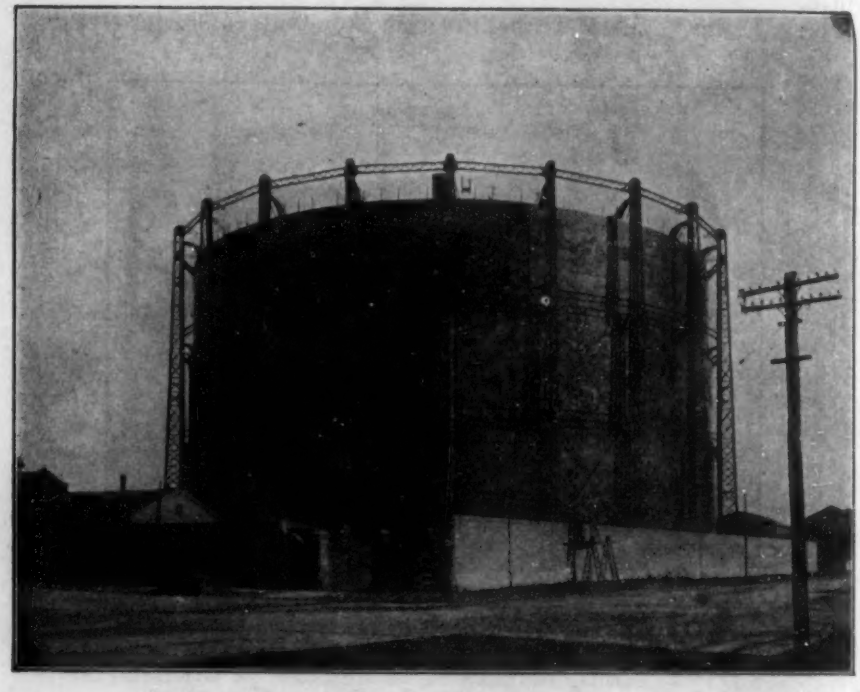

Fig. 18—Two Million Cu. Ft. Gas Holder, Constructed by Welding in Melbourne, Australia

their milk receiving room. Heretofore cement and bituminous flooring were used with more or less leaking and a great tendency to crack. Three hundred thousand pounds of milk enter this room daily, mostly in 100-lb. cans. The plates were cut 4 ft. x 10 ft. x $\frac{3}{8}$ in., planed to a 45 deg. bevel. The floor had to be 100 per cent waterproof and have as great a resistance to shock and abrasion as possible. With this type of construction it was possible to slide cans over a smooth surface, netting a saving on labor alone of about $1,200 annually. (Fig. 15)

One Hundred Foot Welded Tower. This tower was completed in a cave in California and is built up of spiral strips of steel inclosing a spiral stairway. Every joint of the 7200 in the structure was welded by the electric arc. The cost of the completed tower was $3,000 as against the lowest estimate on the riveted structural steel

tower of $12,000. The steel used in the welded tower was slightly over 3 tons. Similar weight of a bolted and riveted structure is 13 tons. (Fig. 19)

Eighty Thousand Barrel Tank. The bottom of a tank 117 ft. in diameter was constructed in the oil fields of the Southwest. Plates were 18 ft. x 6 ft. x 3/16 in., each weighing about 900 lb. (Fig 14)

Welded Floating Roofs. A floating welded roof for a gasoline

Fig. 19—Spiral Stairway 100 Ft. High, Constructed in California Cave

tank 30 ft. in diameter was constructed by the Chicago Bridge and Iron Works to protect gasoline tanks from evaporation and fire hazard.

Arc Welded Radio Towers. Two welded radio towers, 115 ft. high, largely made of steel pipe, were built two years ago at Peking, China. Requirements were to support a horizontal antenna pull of 3000 lb. at a height of 150 ft. and to use a limited ground space with a permanent support. Funds and time were limited. There are several distinct advantages to be found in the design and construction of this tower. First, all members of the tower are round

and hence offer a relatively small resistance to the wind, which is important as a great part of the stresses produced on such a tower is caused by the wind acting on the tower itself. Second, pipe sections give nearly perfect columns, having the great strength with a given amount of metal. Third, the details are so arranged as to make use of nearly all scraps resulting from the cutting of the main members. Fourth, electric welding is much easier, quicker and cheaper than riveting on work of this nature, and if properly done it is just as reliable as riveted work. Fifth, the use of material of light weight permits the easy erection of long shop sections. Sixth, the finished tower has smooth, easy lines and offers a pleasing appearance.

1. Tug boat having a length of 42 ft. beam of 11 ft. and a depth of 6 ft. 6 in. Boat constructed of steel with shell plating 3/16 in., frames 1½ by 1½ in. angles, and bar keel 1 in. by 5 in. Tug compelled in winter to break through ice 8 in. in thickness. Once it was caught between two large ships and her side crushed in 18 in., raising her deck 6 in. This damage was repaired by using hydraulic jack to press the sides out to proper places and neither these extraordinary stresses nor other service conditions have in any way started or cracked the welding.

2. Welded Caisson. An all-welded steel self-floating caisson was constructed in Japan for the 460-ft. dry dock at Hikoshuma dry-dock.

3. Welding pontoon for crane at Kobe plant 65 ft. long, 35 ft. molded breadth and 8 ft. molded depth, having a rectangular form in cross sections.

4. Battle Towing Target. A 172-ft. battle towing target was constructed at the Norfolk Navy Yard by arc welding.

Inspection: One of the greatest handicaps to welding is the contention that welds are lacking in uniformity and that it is not yet possible to tell when a welded joint is good or bad. It is a well-known fact that in a riveted structure not all the rivets have the theoretical strength that they are supposed to have. If the rivet is too cold or the thickness of steel to be riveted too great or the pressure of the riveting machine not sufficient, the rivet is not upset enough to fill the hole and the proper bearing of the rivet upon the plate is not secured.

In his paper on "Applications of Arc Welding to Ship Construction," Mr. Ewertz states:

Riveting, also, has its hazards, for heavy locked up stresses are produced in the driving of a rivet and stresses are set up in the plating nearby due to hammering. It is often impossible with the best workmen to obtain fair rivet holes and therefore rivets are frequently driven into odd shaped holes, adding uncertainty to the results obtained. While the testing of rivets is readily performed,

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NOTE:—The following welded structures are reported by Mr. Ewertz in his paper on application of arc welding to ship construction, published by the American Bureau of Welding.

it is frequently found in tests of compartments that the water produces an excessive strain on the rivets. Again, rivets having passed all the tests during the ship's construction are sometimes found incapable of standing stresses produced by the ship working in a heavy sea.

The vast amount of skilled labor required to properly form the various members of a ship's structure, to make and punch rivet holes, to bolt together and fair up the various parts, is labor that is little understood by the average engineer. The hazards, however, due to human incapability to produce perfect work are offset by the liberal margin for safety allowed for in the classification rules; therefore, we seldom hear of disaster to a ship due to faulty construction.

However, structural engineers will argue that there are enough rivets so that even if 15 per cent of them are bad the factor of safety is such that the riveted joint will withstand the stresses which it meets in service. Moreover, a loose rivet does not necessarily mean that it has no strength. As previously indicated in the report wherever possible, the welded structures should be designed such that there will be a great many welds instead of all the strength concentrated in one place.

The real solution, however, is inspection, proper materials, apparatus and skilled workmen.

It is perfectly possible to have inspectors so trained that during the welding processes they can see whether proper welding is being done. As a matter of fact a good operator knows whether he is doing a good job. Conscientious workmen are quite necessary if the use of welding is to be extended. On a number of occasions prominent welding engineers have expressed an opinion that the skill of welders should be tested before they are put on the important work. This is very readily done but it does not alter the fact that conscientiousness on the part of the workmen is absolutely necessary for under test he may do a 100 per cent job while in service he may be careless.

Another important development which is bound to have its influence is the use of automatic and semi-automatic welding machines thereby eliminating the factor of the operator. These machines have been described in considerable detail at various meetings of the American Welding Society.

Corrosion

The following excerpt on the above subject is taken from Mr. Ewertz's paper:

Corrosion of Arc Weld Metal in Sea Water

A. G. Bissell, of the general engineering department of the Westinghouse Electric and Manufacturing Company, while at the Puget Sound Navy Yard, had an opportunity to examine many arc welds that had been in sea water for various lengths of time.

In no instance was the arc weld metal corroded any more than the surrounding plate material except where it had been used to build up rivet heads on ships' rudders. Unwelded rivet heads in this same vicinity were also badly corroded. From a careful examination of the rudder of the U. S. S. *Arkansas* it was found that both welded and unwelded rivets on the forward end were corroded while a few feet along the side of the rudder were several welded rivets, none of which showed any signs of corrosion. It was concluded at the time that the corrosion was due to the electrolytic action between the steel of the rudder and the bronze propellers, the action being concentrated at the rivet heads.

The only information which the General Electric Company has on the ability of a weld to stand corrosion is that in connection with the 12 ft. cubical tank which was made for the Emergency Fleet Corporation. This tank when completed was exposed to the weather for 5 years and a piece recently cut out of the side, which included a welded joint, showed that the depth of oxidation in the weld was just the same as on the plate, giving evidence that the welded portion is not any more susceptible to corrosion from ordinary weather conditions than the plate itself. The plate was ½ in. ship plate.

Needed Data

There is no question that structural engineers who read this report may be favorably impressed with the possibilities of welding. It is also certain that were they inclined to specify the use the welding they would at once be confronted with the need of certain tests and data that are now lacking. This information would come under the following heads:

1. *Accurate Cost Data.* Making it possible to readily compute the cost of any particular welded structure. The basis for this information is already available. Figures for specific jobs would have to be compiled from experience.

2. *Tensile Strength.* Much information on this subject is already available. It may be necessary to make a few tests on specific types of joints, materials and methods.

3. *Shearing Strength.* A little information is available. Much more is needed.

4. *Resistance to Shock.* In certain instances completed welded structures will have to be tested. In most instances, however, there is enough information already available.

5. *Bending.* Here again tests for bending would have to be made in certain completed structures; the bending qualities of small specimens are well known.

6. *Welding Wire.* Specifications for welding wire found satisfactory in service are already available, having been compiled by an appropriate research committee of the American Welding Society. However, certain tests will have to be made for specific materials to check their merits.

7. *Tests for Operators.* Specifications for making and testing welded test specimens are already available.

8. *Inspection.* Careful instructions will have to be worked out for inspectors. In fact, a short training course might be necessary.

9. *Materials.* It is quite likely that the present quality of steel will be entirely suitable for welding. Closer attention will have to be given to the physical and chemical properties. In all probability closer tolerances and additional chemical and physical requirements will be found necessary.

10. *Design.* This is by far the most important subject that will have to be considered by structural engineers. Designs will have to be developed for specific structures that are suitable only for welding. As previously pointed out in the report, it will be possible with the design of structures, including shapes, methods and materials prepared with only welding in mind, to effect considerable economies and obtain structures that are better than similar riveted ones or ones where both welding and riveting could be used.

11 *Methods of Assembly.* This is a very important feature. Standardization based upon experience will undoubtedly be brought about in time and will be necessitated if lower costs are to result.

Fortunately for the structural engineer there is in existence an internationally known welding research department, known as the American Bureau of Welding. It really is the research department of the American Welding Society and is closely affiliated also with the National Research Council. The Bureau is well organized and has established contacts with testing experts, welding engineers, metallurgical experts, structural engineers and other talent that is needed in these investigations. It also has at its disposal the testing facilities of the several governmental departments, the laboratories of universities and of many private corporations.

A large number of investigations have also been made by the Bureau and reports rendered. A considerable amount of data so obtained is also applicable to work in the structural field.

Conclusions

The following important conclusions seem to the authors worthy of special mention:

1. Electric arc welding possesses possibilities of being used as a means of fabricating structural steel parts with resulting economies and superiority of product.

2. Test data and service experience have already shown that welding can be safely used in structural work if proper regard is given to design, methods, inspection, workmen, materials and specifications.

3. If welding is to be specified, a structure should be designed

primarily for welding, as in this way only will it be possible to get a good job and effect the maximum economies.

4. While a vast amount of data is already available still others will have to be obtained and in particular types of joints, shapes of structural members will have to be developed as a result of welding experience and tests.

5. Structural engineers, steel companies and fabricating companies should get together and cooperate in the preparation of data and specifications which will be of service to the structural engineers and in conducting a comprehensive series of investigations to secure the data and information that are now lacking.

Acknowledgments. The authors wish to acknowledge assistance received from the writings of pioneers in this field such as H. M. Hobart, consulting engineer, General Electric Company; Prof. F. P. McKibben, Union College, Schenectady, N. Y.; Major James Caldwell, managing director, Alloy Welding Processes, Ltd., and E. H. Ewertz, general manager, Moore Plant, Bethlehem Shipbuilding Corporation.

Appendix A

Design for a Riveted Steel Truss for Static Loads*

F. P. McKIBBEN†

Practically all riveted joints depend for their strength upon the shearing value of the rivets or on the bearing of rivets upon plates connected, and it is comparatively easy to substitute electric welding for rivets in many structures without materially changing the present standard forms for steel members, the deposited metal at the weld will be subjected to shearing rather than to tensile stresses. The best data thus far published on shearing strength of deposited metal are those of E. S. Humphreys, Jr., made at the General Electric Company's Schenectady plant and at Union College, published in *Iron Age,* May 25, 1922. The accompanying figures and tables give the results of these tests, which mark such a step forward as to merit some attention. Referring to Figs. 20 and 21 it is seen that each specimen consists of two plates joined together by two splice plates in such a manner that the deposited metal, or beads, runs parallel to the length of the plates and therefore parallel to the tensile pull exerted upon these plates, with the result that the beads are subjected to shear. It is just this action that will be brought upon beads deposited in many joints of electrically welded bridge and roof trusses.

The shearing strength of the bead varies from 31,145 lb. per square inch for the ½-in. bead to 42,000 lb. per square inch for the

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*Taken from an article appearing in the Feb., 1922, issue of the Journal of the A. W. S.

†Professor of Civil Engineering, Union College, Schenectady, N. Y.

¼-in. bead, and the table shows quite conclusively that the smaller the bead the greater is the unit shearing strength in pounds per square inch. It should be pointed out here that when these specimens failed in the testing machine the plane of fracture, i.e, plane of shear, was not the base of the triangular fillet but was on a plane extending from the apex of the triangle perpendicularly to the hypothenuse opposite the plane of smallest shearing area. The plates were of ordinary structural steel quality and the electrode was a standard commercial bare wire, high in manganese and low in carbon, sulphur, phosphorus and silicon. The average shearing strength of the beads for all specimens which failed by shear was 36,310 lb. per square inch.

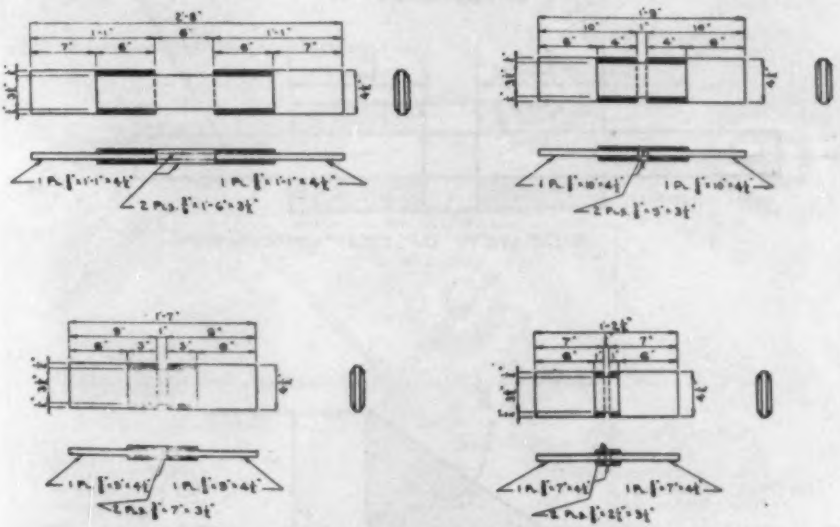


Fig. 20—Details of Test Specimens

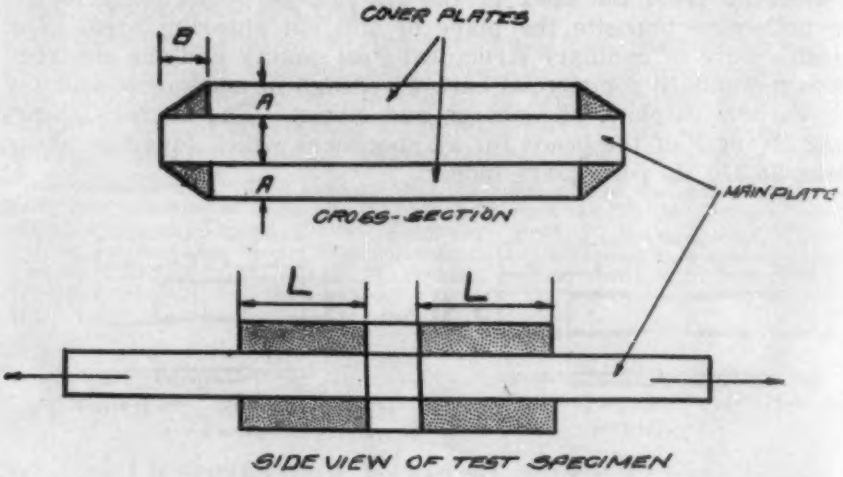
SAFE ALLOWABLE SHEARING STRENGTH FOR BEADS AT 9000 LB. PER SQUARE INCH

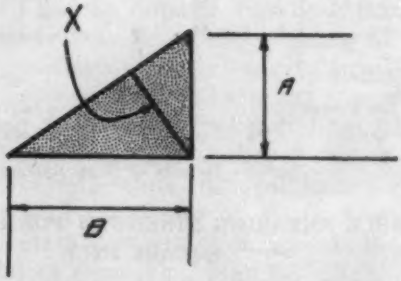
A in.	B in.	X in.	Safe strength per linear inch of bead lb.
½	½	0.355	3195
⅜	½	0.300	2700
⅜	⅜	0.266	2394
¼	⅜	0.203	1827
¼	¼	0.177	1593

If a factor of safety of four be applied, the safe allowable shearing strength per square inch of longitudinal section of bead on the minimum section is approximately 9000 lb. per square inch. Using this value, Table above shows the allowable safe working stresses in pounds per linear inch of bead for beads of varying dimensions.

For example, for a triangular bead ½ in. deep by ½ in. horizontally the minimum shearing section would be 0.355 sq. in., which multiplied by 9000 lb. per square inch, the safe working shearing strength, gives 3195 lb. per linear inch of bead.

In Fig. 22 is shown a preliminary design for an arc welded truss,





DETAILS OF TEST SPECIMEN

Fig. 21

having a span of 56.4 ft., and carrying a load of 126,000 lb. at the center point C. The following safe unit stresses have been used:

Tension 16,000 lb. per square inch.

Compression $15{,}000 - 50\frac{L}{r}$

L = Length of member: r = Radius of gyration of cross-section.

Shearing in beads — 9000 lb. per square inch.

All welds are of the fillet type, triangular in cross-section and

the strength of these fillets are shown in the upper left-hand corner of Fig. 22, the 7/16-in. x 7/16-in. fillet having a safe working strength per linear inch of 0.31 x 9000 = 2790 lb.; and the ½-in. x ½-in. fillet a working strength of 0.335 x 9000 = 3195 lb. To determine the required length of fillet, or bead, to develop in shear a safe strength equal to the stress exerted by the member BC is merely necessary to divide the stress, 89,200 lb. by the safe shearing strength of a ½-in. x ½-in. bead per linear inch, i.e., by 3195 lb., thus giving 27.8 in., or 14 in. for each of the two angles of

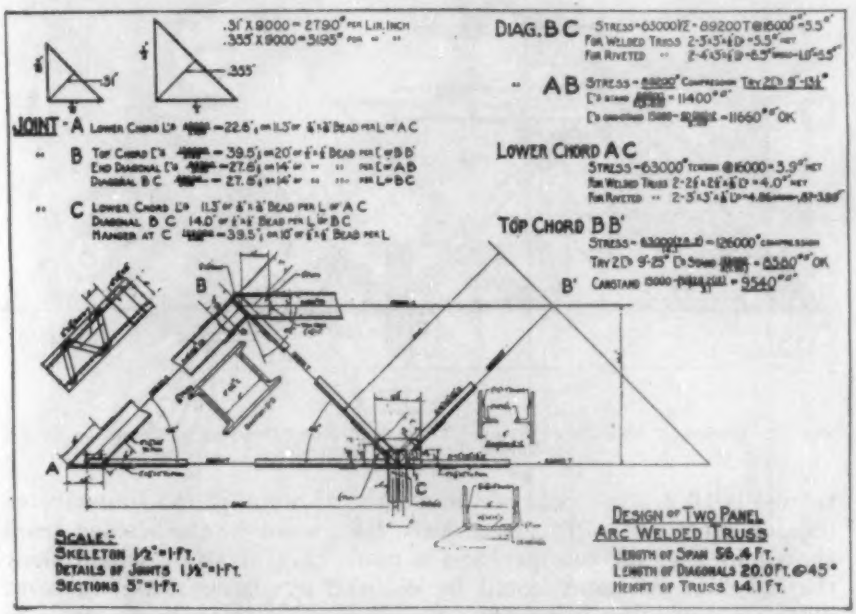


Fig. 22—Design of Two Panel Arc Welded Truss

member BC. The compactness of the joints in the electrically welded truss is very noticeable and there is a great saving of material in such joints over the ordinary type of riveted joint. Just what the saving in cost may be is at present a matter of conjecture because we have not had sufficient experience to secure accurate cost data on electric welding of such structures.

Another very important advantage which the welded truss has over the riveted truss consists in saving material in tension members due to the reduction of cross-section in riveted trusses caused by the rivet holes. For example, in the welded truss shown in Fig. 22 the tension member AC is made up of two 2½-in. x 2½ x 7/16-in. angles with a cross-section of 4 sq. in., and this is also the net section, as there is no reduction of area. In the riveted truss (Fig. 23), this lower chord member AC is made up of two 3-in. x 3-in. x 7/16-in. angles with a cross area of 4.86 sq. in., but as the rivet holes take out 0.87 sq. in. the net is only 3.99 sq. in. The

diagonal BC in the riveted truss also suffers loss due to the presence of rivets. The saving of weight in the four tension members of the welded truss over the corresponding members of the riveted truss due to reduction of area caused by rivets alone is 304 lb. The weight of steel in the angles of the four tension members of the welded truss is 1520 lb., and weight in the four corresponding members of the riveted truss is 1824 lb. The saving by the use of the welded truss so far as main tension members are con-

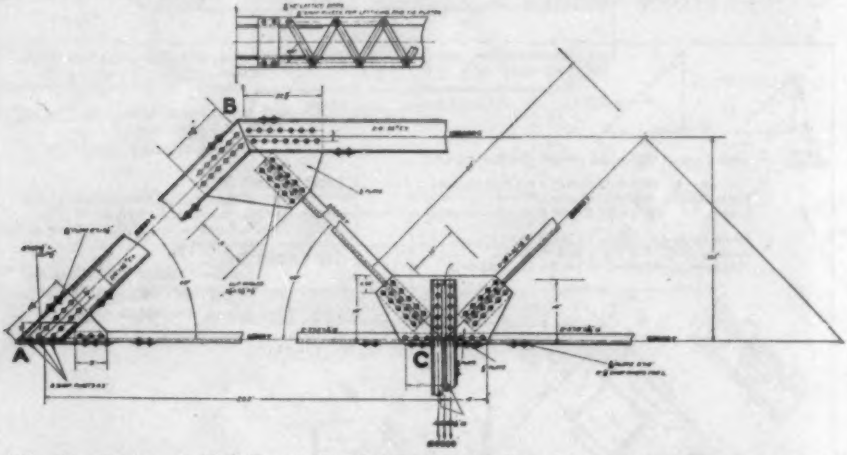


Fig. 23—Design of Two Panel Riveted Truss with Same Loading and Span as for the Welded Truss of Figure 22

cerned is 16 2/3 per cent of the weight of metal in the four riveted tension members. No rivets have been used in the welded truss shown in Fig. 22, but perhaps a more careful study would show that greater economy could be secured by using rivets in some places and welding in others. For example, it may be desirable to use rivets in the lattice bars of the compression members which in Fig. 22 are shown welded.

Appendix B

Welded Truss

W. L. WARNER†

The design of a welded truss is a relatively simple matter when the style of the truss and the loading are known. At the present time, however, so little is known concerning the strength of various types of structural welds that the complete design of a steel structure is out of the question. In Fig. 24 is shown a small riveted truss which was designed for a span of 48 ft. for railway service.

†Industrial Engineering Department, General Electric Co.

It is the author's purpose now to redesign this truss for welding. It should be borne in mind, however, that the greatest economy will result only when the truss or structure is designed for welding in

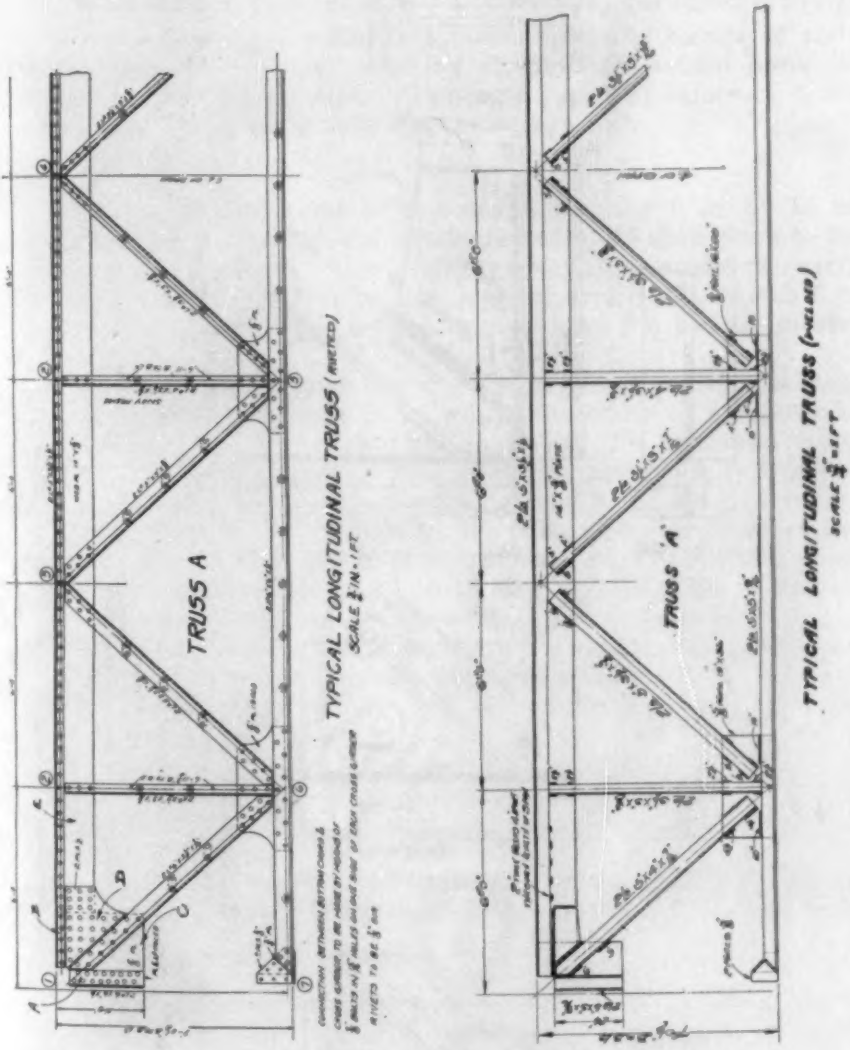


Fig. 24—Welded and Riveted Truss

the first place instead of designing it for riveting and then redesigning for welding. This point will be explained in the discussion.

In the various steps of the design which follow the safe loads for various sizes of bead are those given by Prof. F. P. McKibben in his paper "Arc Welding of Steel Structures." These are as follows:

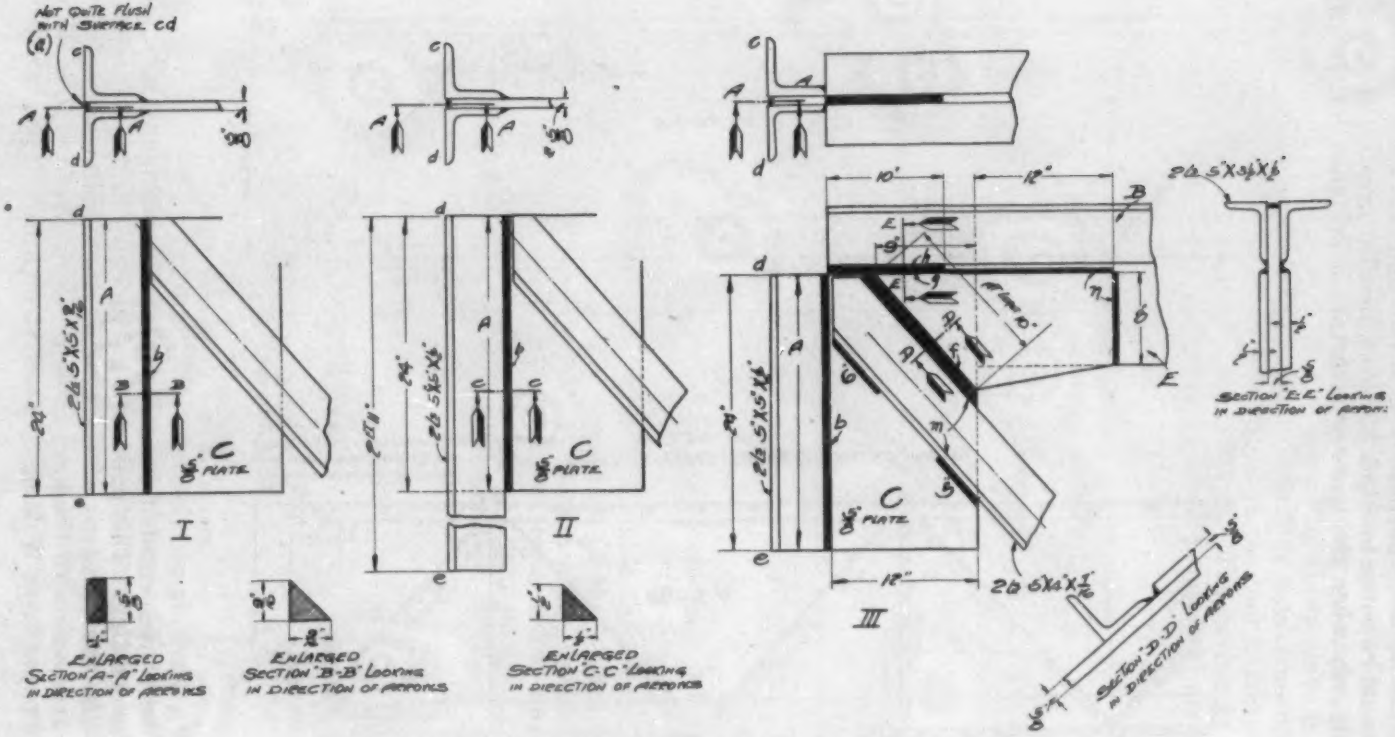

NOT QUITE FLUSH WITH SURFACE cd
(a)
2 ⌊s 5"X3½"X⅝"
2 ⌊s 5"X3½"X⅝"
C ⅝" PLATE
I
II
III
2 ⌊s 6"X4"X⅞"
ENLARGED SECTION "A-A" LOOKING IN DIRECTION OF ARROWS
ENLARGED SECTION "B-B" LOOKING IN DIRECTION OF ARROWS
ENLARGED SECTION "C-C" LOOKING IN DIRECTION OF ARROWS
SECTION "D-D" LOOKING IN DIRECTION OF ARROWS

Fig. 25—Details of Welding Truss Shown in Fig. 24

¼ in. by ¼ in. bead.....1593 lbs. per linear inch
⅜ in. by ⅜ in. bead.....2394 lbs. per linear inch
7/16 in. by 7/16 in. bead.....2781 lbs. per linear inch
½ in. by ½ in. bead.....3195 lbs. per linear inch
9/16 in. by 9/16 in. bead.....4770 lbs. per linear inch

NOTE: The above values are based upon the results of tests which gave the average shearing strength of welded beads as 36,310 lbs. per square inch. Allowing a factor of safety of 4, the safe allowable stress is 9000 lbs. per square inch.

End Connecting Angles (A)

These members consist of two angles 6 in. by 6 in. by ½ in. each, with 24 rivet holes, and are connected by 16 shop rivets to the ⅝-in. gusset plate (c). The safe load which these angles can carry is limited by the shearing section A shown in Fig. 25, Sketch I, or by the strength of the 16 rivets shown at joint No. 1 of the riveted truss.

The net section through one line of 8 rivets of angles A is equal to the total length, about 26 in. minus the width of 8 rivet holes multiplied by the thickness of one angle, and this figure multiplied by two for the two angles. This gives the distance A in Sketch I as 18 in. to give the same shearing strength for the two welded angles as for the riveted angles. We must now consider the weld.

There are 16 shop rivets in bearing on one ⅝-in. plate, which gives an allowable load of $16 \times 13{,}130 = 210{,}000$ lbs. The safe load for shear which can be carried by the two angles is $18 \times 1 \times 10{,}000 = 180{,}000$ lbs. The shearing of the angles rules in this case and we must have a weld which will carry at least 180,000 lbs. from gusset plate C to angles A. We will, however, design from the load supported by the rivets.

The net area of each angle on a horizontal plane $= 5.75 - 2\ (1 \times ½) = 4.75$ sq. in. We can use either 2— 5 in. x 5 in. x 9/16 in. angles or 2—5 in. x 5 in. x ½ in. angles with areas of 5,31 sq. in. or 4.75 sq. in. respectively.

Assuming that we use the former size of angle, then, we can use a 9/16-in. triangular bead, which is good for 4770 lbs. per linear inch. There would be required, then, $\frac{210{,}000}{4770} = 44$ in. of weld. To be safe we will use 48 in. and weld along the edges shown at (b) in the side view, Sketch I, which gives us the required length of weld.

It can be easily seen that were the angles welded only along the edge (b) a bending moment would be introduced into the weld in addition to the shear which it is designed to carry. The joint would be unsafe. We must, therefore, make a weld also as shown at (a) Sketch I. At this point it must be brought out that we have no data on the strength of the type of joint just mentioned. We are relying on it in this case simply to prevent a bending moment in the weld at (b).

Let us consider for a moment the connection of the angles A to the abutment or other support along the plane (cde) Sketch I. The load is 210,000 and we will use a 9/16-in. bead. There is required 44 in. and we will use 48 in. The angle 24 in. long is then sufficient and we will put a 9/16-in. bead along each angle at (dc).

It should be noted that the weld at (a) should not project beyond the plane (cd).

If now we should desire to use two angles 5 in. x 5 in. x ½ in. instead of those shown in Sketch I, the length must necessarily be more than 24 in., since a ½-in. bead is only good for 3195 lbs. per inch of length. This would make a more unsightly connection, as shown in Sketch II. The length required is $\frac{210{,}000}{3195} = 66$ in. and we should use about 70 in. This would mean about 35 in. along (dc) on each angle. (See Sketch II).

Assuming that the weld as shown at (a) Sketch II is equivalent to two ¼-in. triangular beads with a safe load per linear inch of 1593 lbs., then the length of 24 in. is sufficient in conjunction with the weld at (b). The preference, however, would be for the setup as shown in Sketch I.

Now let us consider the real limiting strength of the riveted angles. We have found that the maximum load which the riveted angles A will stand safely is 180,000 lbs. and that the net cross sections is 18 in. long. In designing the welded joint the first question that arises is with regard to the required length of 9/16 in. or ½ in. angles. Using the former, the length of angles is $\frac{18}{1\frac{1}{8}} = 18 \times 8/9 = 16$ in. The length of the ½-in. angles must necessarily be the same as the riveted angles minus the eight rivet holes. This length is 18 in.

The number of inches of weld required for this joint, using the 9/16-in. angles, is $\frac{180{,}000}{4770} = 38$ in.

We will use 40 in. and put 16 in. on each angle. Weld also as shown at (a) Sketch I to take care of the extra 8 in. of weld which cannot be obtained otherwise unless the angles are cut 20 in. long instead of 16.

Using the ½-in. angles, the number of inches of weld required $\frac{180{,}000}{3195} = 57$ in. We would use about 60 in., which would require angles about 30 in. long.

Connection of ½-in. Plates D to Gusset Plate C

There are two plates D ½ in. thick which are connected to the ⅝-in. gusset plate C by 15 shop rivets in bearing on the ⅝-in. plate. The load to be carried is then 13,130 × 15 = 196,950 lbs. We can use a ½-in. triangular bead which has a safe load of 3195 lbs. per linear inch. The total number of inches of weld required

= 196,950 divided by 3195 = 61.6 in. We will use 64 in. and put 32 in. along each plate.

Upon closer inspection we find that probably 15 rivets are unnecessary for making this connection. Undoubtedly 9 rivets are sufficient and the other six are used only for adornment. This situation is brought out by reason of the fact that 9 rivets carry the whole stress from web plate E to plates D. This second consideration gives us $\frac{9 \times 13{,}130}{3195} = \frac{118{,}170}{3195} = 37$ in. We will use 40 in. and put 20 in. on each plate, as shown by (f) and (g) of Sketch III. We are rather uncertain as to the strength of a bead in the position of (f) and need test data on this point.

Connection of Top Chord Angles B to Gusset C

For the top member we have two angles 5 in. x 3½ in. x ½ in. There are 5 shop rivets connecting the top chord angles B to the gusset plate C. These rivets have an allowable carrying capacity of 5 × 13,130 = 65,650 lbs. If we use a ½-in. bead we will require $\frac{65{,}650}{3195} = 20.5$ in. of weld. We will use 24 in. In order to secure the proper amount of weld we will put 10 in. along one edge of each angle shown at (h) Sketch III and then put a weld of 10 in. on the top between the angles as shown at (k) Sketch III. The details of this last are shown at (e) Sketch III. We have no test data on the strength of a weld of this nature, but we assume that 10 in. of this type of weld will at least be equivalent to 4 in. of straight triangular bead.

Connection of Top Chord Web E to Plates D

There are 9 shop rivets connecting two ½-in. plates to one ⅝-in. plate. The limiting feature in this case is bearing on the ⅝-in. plate. The allowable load is then 9 × 13,130 = 118,170 lbs. Using ½-in. bead there would be required approximately $\frac{118{,}170}{3195} = 37.1$ in. of weld. We will use 40 in. and put 20 in. on each plate, as shown at (n) Sketch III.

Member 1 — 6

This member consists of two angles 6 in. x 3½ in. x 7/16 in. having a net area of 3.533 sq. in. each. The allowable tension is then 7.066 × 16,000 = 113,000 lbs. For welding we can use two angles 5 in. x 4 in. x 7/16 in., and we will therefore use a 7/16-in. bead. The number of inches of weld required $= \frac{113{,}000}{2781}$ =40.7. We will use 44 in. and put 11 in. on each side of each angle, as shown at (m) Sketch III.

It should be noted that on all tension members we can save weight by reducing the size of the member, since originally it was

per linear inch. The total number of inches of weld required

designed on a net section. On the other hand, compression members cannot be reduced, since they were originally designed on the gross section of the angles using the column formula $(12{,}000 - 70\ \frac{l}{r}$ gross area, where l = length of member and r = least radius of gyration of the cross section of the member.

In the original design the tension members were designed with a net area of cross section greater than the amount necessary to carry the allowable load. In redesigning for welding from the riveted design the net area of the welded member is necessarily somewhat greater than that of the riveted member, so that the resulting design has a cross section and weight too great for the most economical design. This situation is inevitable when designing from a riveted design without knowing the actual stresses which will be imposed.

In the case of compression members the excess of strength over that required is considerably greater than in the case of the tension members. For instance, consider compression member 2—6, for which three rivets are used at each end to make the connections. The load which these three rivets can carry is 39,390 lbs. Undoubtedly three rivets are more than enough to carry the load, but two rivets are not enough, as is shown by the following:

Consider the column formula $(12{,}000 - 70\ \frac{l}{r}) \times$ area of member. The load allowable on this member by this formula is $(12{,}000 - 70\ \frac{8 \times 12}{1.1}\ 4.6 = 27{,}140$ lbs.

This shows that by designing the welded joint directly from the number of rivets we are making the joint stronger than necessary. In this instance we have recommended using 20 in. of weld when 12 in. is sufficient to develop the full strength of the member in compression.

The above discussion brings out the point previously stated that the design of a truss from a riveted design is not as economical as the design of the same truss direct from the loading values. The discussion also illustrates the freedom which is allowed the designer of a welded structure because of the great elasticity of the welding process. It is possible to put just enough welding on and not necessary to put more than enough to secure the proper strength.

The same general scheme holds true for the remainder of the truss and a general outline of the design of the various joints follows:

Joint No. 2
Member 2-6

Structural Forms, 2Ls 3½ in. by 3 in. by ⅜ in.
Allowable load = 3 rivets in bearing on ⅝-in. plate = 3 × 13,130 = 39,390 lb.
Use ⅜-in. bead for the weld.

weight by reducing the size of the member, since originally it was

Total inches of weld required $= \frac{39{,}390}{2394} = 16.5.$

Use 20 in.
On each angle put 5 in. of weld on each side.
Do the same at Joint No. 6 for this member.

Joint No. 3
Member 3-6

Structural Forms, 2Ls 5 in. by 3½ in. by ⅜ in.
Allowable load = 6 rivets in bearing on ⅝-in. plate
$= 6 \times 13{,}130$
$= 78{,}780$ lb.
Use ⅜-in. bead for the weld.

Total inches of weld required $= \frac{78{,}780}{2394} = 33$ in.

Use 36 in.
On each angle put 9 in. of weld on each side.
Do the same at Joint No. 6 for this member.

Joint No. 3
Member 3-5

Structural Forms, 2Ls 5 in. by 3 in. by ⅜ in.
Net area $= 2\ (2.86 - 1.0 \times ⅜) = 2\ (2.86 - 0.375)$
$= 2\ (2.485) = 4.97$ sq. in.
Allowable load $= 5.0 \times 16{,}000 = 80{,}000$ lb.
For welding use 2Ls 3½ in. by 3 in. by 7/16 in.
Net area = 2.65 sq. in.
Use 7/16-in. bead for the weld.

Total inches of weld required $= \frac{80{,}000}{2781} = 29.0$ in.

Use 32 in.
On each side 3½ in. by 3 in. by 7/16 in. L, put 8 in. of weld on each side.
Do the same at Joint No. 5 for this member.

Member 2-5

Structural Forms, 2Ls 4 in. by 3½ in. by ⅜ in.
Allowable load = 3 rivets in bearing on ⅝-in. plate $= 3 \times 13{,}130$
$= 39{,}390$ lb.
Use ⅜-in. bead for the weld.

Total inches of weld required $= \frac{39390}{2394} = 16.5.$

Use 20 in.
On each angle put 5 in. of weld on each side.
Do the same at Joint No. 5 for this member.

Joint No. 4
Member 4-5

Structural Forms, 2Ls 3½ in. by 3 in. by ⅝ in., wt. 7.9 lb.

Allowable load = 4 rivets in bearing on $\frac{5}{8}$-in. plate = 4 × 13,130 = 52,520 lb.
Use $\frac{3}{8}$-in. bead for the weld.

Total inches of weld required = $\frac{52520}{2394}$ = 22.

Use 24 in.
On each put 6 in. of weld on each side.
Do the same at Joint No. 5 for this member.
Remainder of Truss is the duplicate of this half shown.

Bottom Chord

Structural Forms, 2Ls 6 in. by 6 in. by $\frac{1}{2}$ in., wt. 19.6 lb.
Net area = 2 (5.75 — 1.0 × $\frac{1}{2}$) = 2 (5.75 — 0.500)
= 2 (5.25) = 10.50 sq. in.
Use 2 Ls 5 in. by 5 in. by 9/16 in.

Joint No. 7

Connecting Angles to $\frac{3}{4}$-in. Plate

Structural Forms, 3 shop rivets in double shear = 3 × 14,430 = 43,290 lb.
Use 9/16-in. bead.

Total inches of weld required = $\frac{43,290}{4770}$ = 9.1 in.

Put 6 in. on each angle cutting L at 45 deg.

Connecting $\frac{3}{8}$-in. Plate to $\frac{3}{4}$-in. Plate

Structural Forms, 3 field rivets in double shear = 3 × 12,030 = 36,090 lb.
Use $\frac{3}{8}$-in. bead.

Inches of weld required = $\frac{36,090}{2394}$ = 15.1.

Use 16 in.
Put 8 in. on each plate.

Joint No. 6

Gusset Plate

Structural Forms, one $\frac{5}{8}$-in. plate, 11 shop rivets.
Allowable load, bearing on $\frac{5}{8}$-in. plate, 11 × 13,130 = 144,430 lb.
Use 9/16-in. bead for the weld.

Total inches of weld required = $\frac{144430}{4770}$ = 30.4 in.

Use 40 in.
Put 20 in. on each angle.

Joint No. 5

Gusset Plate

Structural Forms, 11 shop rivets at 13,130.
Use 20 in. on each angle, as for Joint No. 6.

At this point it should be stated that as the art of welding be-

comes more and more an important factor in the structural field, standardized designs will be evolved which will render the design of welded structure more simple. In the present instance some of the joints used might be considered crude and might be improved upon, but it should be borne in mind that we have no practical data on this phase of the subject.

The writer desires to acknowledge the great assistance rendered by Prof. Frank P. McKibben of Union College, who assisted materially in the preparation of this design, both with regard to methods of designing the welds and many helpful criticisms on the subject matter.

The Oxy-Acetylene Torch as a Tool for the Erection of Large Structures*

W. SPRARAGEN†

Engineers are not altogether familiar with the possibilities of the welding and cutting torch as applied in the structural field. As a matter of fact the use of the torch has been adopted by all of the large industries for the cutting of metals either for scrap or demolition purposes or in production work. In the hands of a skilled operator the torch is capable of making a cut which, with or without a small amount of grinding, is smooth enough for most purposes.

The uses to which hand-operated and machine-operated cutting torch can be put to in manufacturing, ship building, car building, boiler making, fabricating and repair work are legion. In fabricating shops the cutting torch is invaluable; steel beams, angles, channels and other structural shapes may be cut and trimmed to any angle required with the torch at a fraction of the expense of cutting mechanically. The process is especially valuable in the field where ordinary cutting machines are not available.

If welding is to be used as a method of fabricating structures, whether the process be electric, spot or gas welding, a cutting torch will soon demonstrate its efficiency and superiority over other methods. With welding, greater tolerances in size will be permissible and very often the cutting may be done in the field as found necessary. It matters little what the shape to be cut may be. A cutting torch in nearly every case can do the work.

Automatic and semi-automatic cutting machines have been developed to allow cutting after complicated patterns or where simple operations are repeated a great many times.

The use of the blow pipe in the structural welding field, however, has both limitations and capabilities. The limitations are chiefly caused by certain inherent features due to the method of heating.

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*To be presented at the Fall Meeting of the A. W. S., Cleveland, October, 1924.

†Secretary, American Bureau of Welding.

Allowable load = 4 rivets in bearing on 5/8-in. plate = 4 × 13,130 = 52,520 lb.
Use 3/8-in. bead for the weld.

$$\text{Total inches of weld required} = \frac{52520}{2394} = 22.$$

Use 24 in.
On each put 6 in. of weld on each side.
Do the same at Joint No. 5 for this member.
Remainder of Truss is the duplicate of this half shown.

Bottom Chord

Structural Forms, 2Ls 6 in. by 6 in. by 1/2 in., wt. 19.6 lb.
Net area = 2 (5.75 — 1.0 × 1/2) = 2 (5.75 — 0.500)
= 2 (5.25) = 10.50 sq. in.
Use 2 Ls 5 in. by 5 in. by 9/16 in.

Joint No. 7

Connecting Angles to 3/4-in. Plate

Structural Forms, 3 shop rivets in double shear = 3 × 14,430 = 43,290 lb.
Use 9/16-in. bead.

$$\text{Total inches of weld required} = \frac{43,290}{4770} = 9.1 \text{ in.}$$

Put 6 in. on each angle cutting L at 45 deg.

Connecting 3/8-in. Plate to 3/4-in. Plate

Structural Forms, 3 field rivets in double shear = 3 × 12,030 = 36,090 lb.
Use 3/8-in. bead.

$$\text{Inches of weld required} = \frac{36,090}{2394} = 15.1.$$

Use 16 in.
Put 8 in. on each plate.

Joint No. 6

Gusset Plate

Structural Forms, one 5/8-in. plate, 11 shop rivets.
Allowable load, bearing on 5/8-in. plate, 11 × 13,130 = 144,430 lb.
Use 9/16-in. bead for the weld.

$$\text{Total inches of weld required} = \frac{144430}{4770} = 30.4 \text{ in.}$$

Use 40 in.
Put 20 in. on each angle.

Joint No. 5

Gusset Plate

Structural Forms, 11 shop rivets at 13,130.
Use 20 in. on each angle, as for Joint No. 6.

At this point it should be stated that as the art of welding be-

comes more and more an important factor in the structural field, standardized designs will be evolved which will render the design of welded structure more simple. In the present instance some of the joints used might be considered crude and might be improved upon, but it should be borne in mind that we have no practical data on this phase of the subject.

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If welding is to be used as a method of fabricating structures, whether the process be electric, spot or gas welding, a cutting torch will soon demonstrate its efficiency and superiority over other methods. With welding, greater tolerances in size will be permissible and very often the cutting may be done in the field as found necessary. It matters little what the shape to be cut may be. A cutting torch in nearly every case can do the work.

Automatic and semi-automatic cutting machines have been developed to allow cutting after complicated patterns or where simple operations are repeated a great many times.

The use of the blow pipe in the structural welding field, however, has both limitations and capabilities. The limitations are chiefly caused by certain inherent features due to the method of heating.

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†Secretary, American Bureau of Welding.

For example, in certain complicated joints, such as would be necessitated by the use of present day structural members, considerable difficulties might be experienced from distortion. On the other hand, it might be possible to substitute types of members such as pipes where these limitations will be removed. The oxy-acetylene flame in the hands of a competent welder can produce a joint that is oil, water and gas tight. In many instances this feature alone would justify its use even if the cost were the same or greater than a similar riveted structure. However, it is generally found that

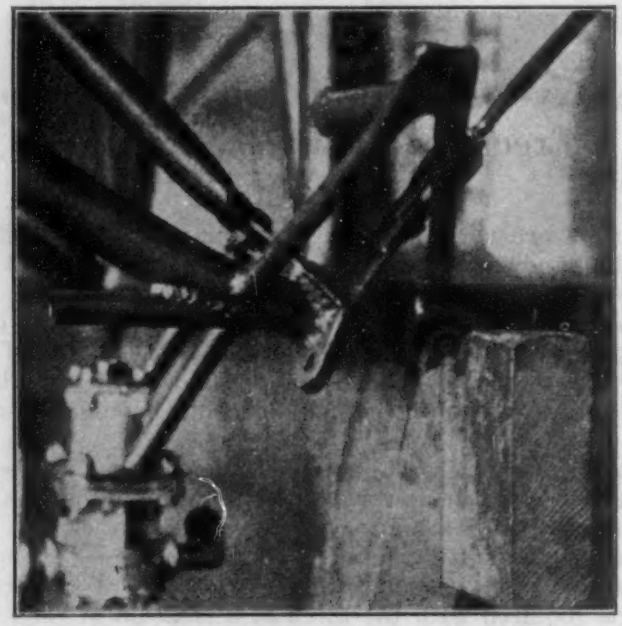

Fig. 1—Oxy-acetylene Welded Joint Used in Aeroplane Construction

with a proper design and management the cost of welding is considerably lowered.

The author does not claim to be an expert in this field and has therefore taken the liberty of citing examples of welded structures that have already been built by the gas welding process.

A 50,000 cu. ft. holder is being built by the oxy-acetylene process in Tulsa, Okla. The water tank is 53½ ft. in diameter by 26½ ft. high.

Two 1000-barrel oil storage tanks have been constructed for a pipe line company in Ohio. These tanks are 22 ft. in diameter by 18 ft. high and made of ¼-in. steel plates with a light steel roof.

The Prairie Pipe Line Company has constructed several buildings made from welded pipe by using second-hand or junk pipe. The most important have been two pumping station buildings, each 40 ft. by 50 ft.; one warehouse and shop building combined, with

dimensions of 50 by 125 ft.; one tool house building 25 by 48 ft., and some smaller buildings, such as manifold houses, garages, etc.

The reliability of welded pipe joints is illustrated by the use of the oxy-acetylene flame in the construction of tubular frame work in aeroplanes. One of these joints is shown in the accompanying sketch. Some tests of these welded splices are made by mitering the tubing and welding the mitered sections together and has shown a tensile strength of 4505 lbs.

At Birmingham, Ala., a tank 22 ft. in diameter and 30 ft. high was constructed by the oxy-acetylene process. The plates were made of ¼-in. steel.

A frame building and staging for a riveted tank was constructed by the Title Refining Company by the oxy-acetylene process. A large construction of this kind is fabricated in part or entirely of scrap pipe, short ends in some instances being butt welded together to make the required length. In case of over-length a cutting blow pipe is used to reduce the pipe to specifications. Design and structural plans for frames and staging of this kind are carefully worked out by the engineer as much as would be necessary if the structures were bridges.

Welded Flag Pole. A 110-ft. flag pole was welded in August, 1918. The pole starts with 10⅝-in. oil well casings and tapers to 3 in., capped with a revolving halyard and gold ball.

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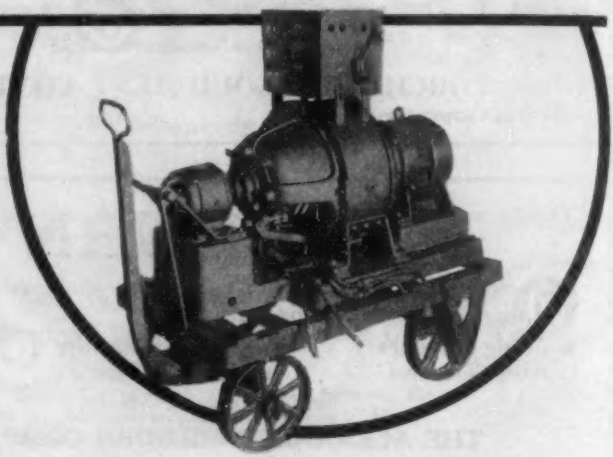

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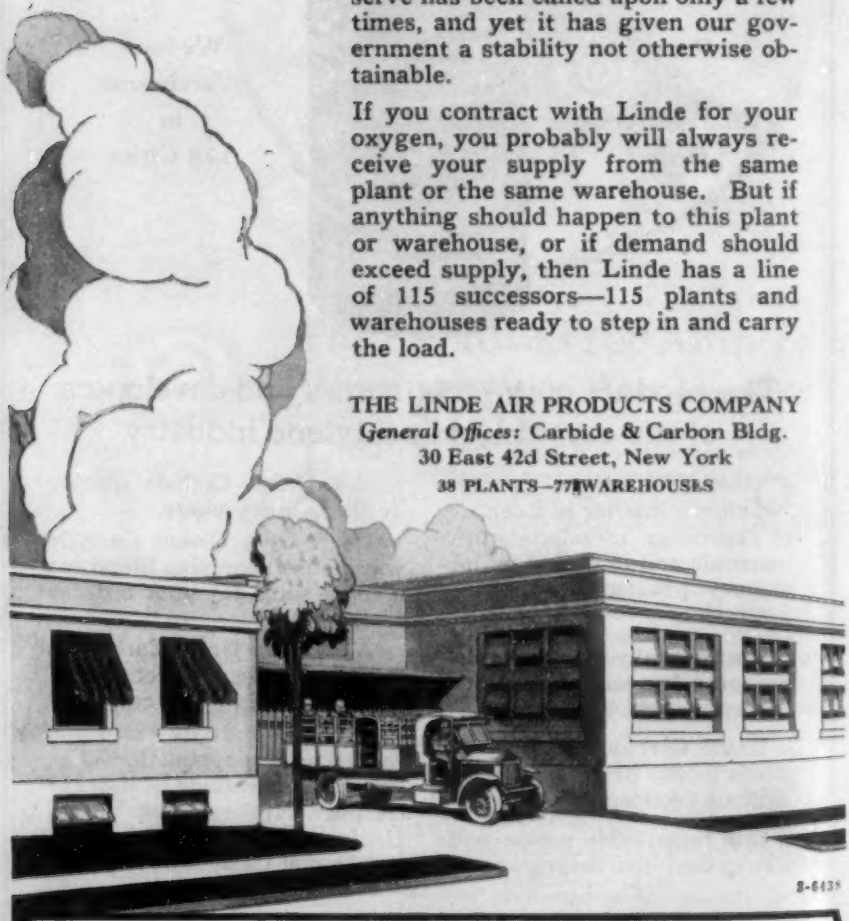

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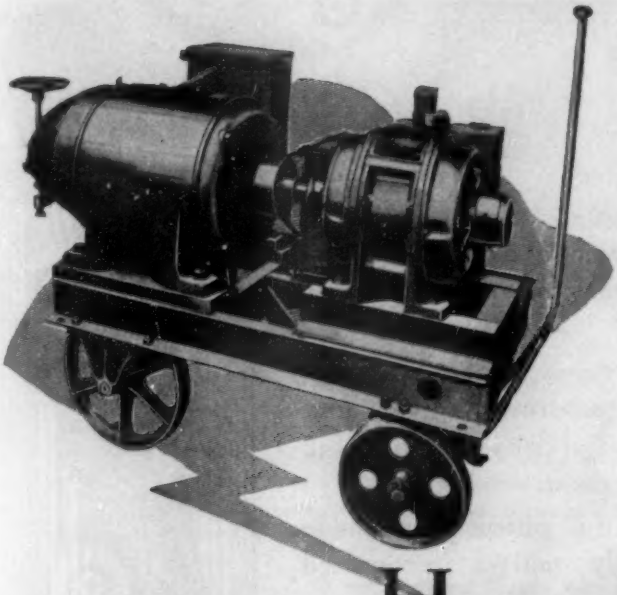

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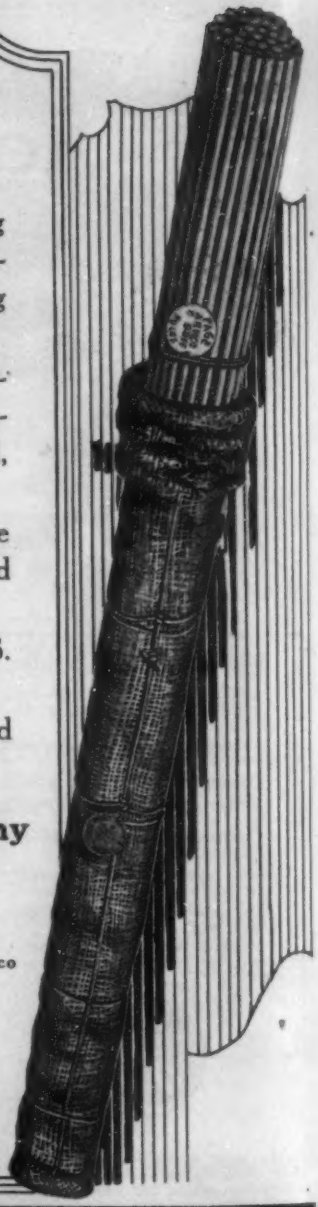

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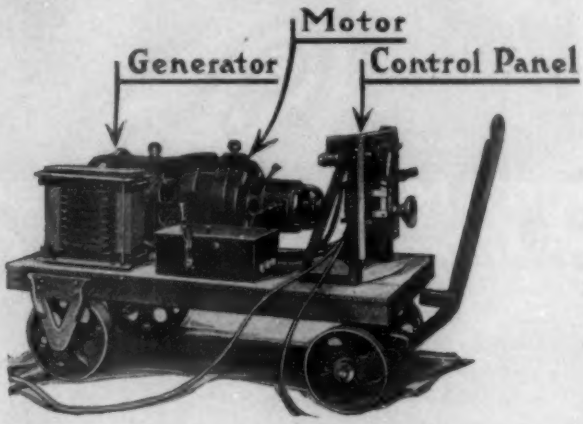

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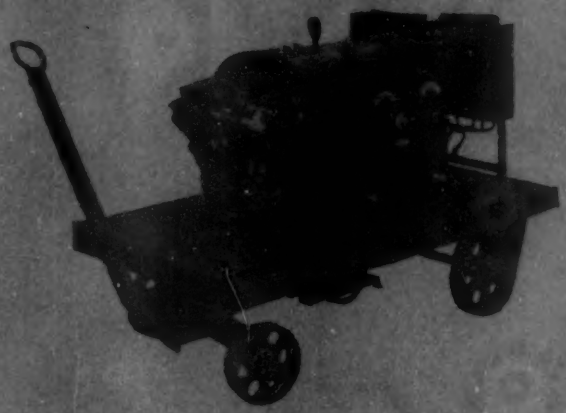

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